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THE ROAD MAKERS' LIBRARY

VOLUME I

ROAD MAKING AND ADMINISTRATION

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ROAD MAKING AND ADMINISTRATION

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OTHER WORKS by DR. PERCY E. SPIELMANN

GENESIS OF PETROLEUM, ERNEST BENN LTD., 1923.
CONSTITUENTS OF COAL TAR, LONGMANS, GREEN & CO., 1924.
BITUMINOUS SUBSTANCES, ERNEST BENN LTD., 1925.
ASPHALT ROADS (*with A. C. Hughes*), EDWARD ARNOLD & CO.,
1936 ; 2nd Ed. in Press.

By ERNEST J. ELFORD

ORGANIZATION AND ADMINISTRATION OF A MUNICIPAL
ENGINEER'S AND SURVEYOR'S DEPARTMENT
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PREFACE TO THE FIRST EDITION

This book is not a text-book in the narrow sense. It assumes a knowledge in the Reader of the general principles and many details of road making ; and on this, as a basis, it attempts to answer the question ' How are things done now in Great Britain—and why ? ', and also to give assistance to the young Engineer and Surveyor in widening the knowledge he may already have of his responsibilities and resources.

This attitude to the subject leads to the advantageous exclusion of much detail of processes and plant that is accessible elsewhere or that can be obtained from the indications that are given. The position has not been interpreted so narrowly as to exclude information that is not ordinarily available or not usually collated, or matter that is of particular interest or usefulness, and indicative of current development.

Generally, in order to avoid invidiousness, descriptions of proprietary articles have been omitted, partly on account of their profusion or the difficulty of their selection, and also of the frequent paucity of available data : lists of these are easily obtainable elsewhere. At the same time a narrow attitude has been avoided, and in some cases products of firms have been referred to by name when their exclusion would have lowered the value of the book by the omission of information that the Reader has a right to expect.

Similarly, acknowledgment has to be made for illustrations courteously supplied by certain firms ; but many of these are intended to be typical only, and it must not be assumed that the products of such firms are necessarily superior to those of other firms.

It may be well to emphasize that the Authors have been careful to preserve a strict impartiality of mind in the presentation of their complex subject. One of their aims has been that of showing Great Britain's resources in road-making materials and plant : but, in this connection, there has been a strict independence of their text from any commercial influence.

Detailed cost of construction has been omitted, as such figures are continuously varying and those that obtain on the date of publica-

tion of this book would soon become misleading ; but comparative costs have been given when likely to be of value.

First-hand information has been sought from many individuals and firms ; and if some of those who have taken the trouble to respond to inquiry—and these have been many and the information they have supplied has usually been full and even lavish—do not recognize in the book all that they have sent, they can rest assured that it has been of great indirect when not of direct value, and the Authors are very grateful to all for assistance so courteously accorded to them. Similarly, thanks are offered to those many writers, here and abroad, for the use of published information to which detailed reference has not always been practicable.

The Authors take pleasure in recording their especial thanks for assistance or interest shown in the preparation of the book by :

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The Limmer and Trinidad Lake Asphalt Co. Ltd. (Messrs. A. W. Attwood, D. C. Broome, V. L. Hope),

The Mountsorrel Tarred Macadam Co. Ltd. (Lieut.-Colonel C. H. Martin),

The Road Emulsion and Cold Bituminous Roads Association
(Brig.-General E. G. Wace, C.B., D.S.O., Chairman, and many
constituent firms).

P. E. S.

E. J. E.

PREFACE TO THE SECOND EDITION

At the time when the First Edition of this book appeared, rapid developments were taking place in road science and research and trials, and a steady flow of new and important information was already replacing some of the earlier matter which was partly guesswork and half-truths, unco-ordinated and incomplete.

Confidence in this growing understanding of road problems has led to a great change in the road-making industry. Clarified knowledge and orderliness of thought and action have resulted in and through the standardization of many materials and processes. As a result of this, some matters which were discussed in the earlier edition of this book are now to be found in the publications of the British Standards Institution, which contain many important technical details incidental to standardization.

The war years have diverted much attention from roads to aeroplane runways and other military requirements, but the developments which have taken place have been important and even striking.

This volume (No. I.) of *The Road Makers' Library* gives consideration to the whole subject in sufficient detail to be generally useful, and forms an introduction to the Series. The welcome given to it has been gratifying. The succeeding volumes are highly specialized and have gone more deeply into the various sections of the subject. Several more will appear in due course to complete the detailed treatment of the wide range of sub-sections covered by the title of Vol. I. Attention is drawn to this, so as to avoid repeated references throughout these pages to details and elaborations in the other volumes. A list of volumes already published is provided on page 462 to assist readers who desire more detailed and elaborate information on a particular subject.

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The British Standards Institution for permission to reproduce the chart of Viscosity Equivalents from B.S. 76 : 1943.

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P. E. S.
E. J. E.

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ROAD MAKING AND ADMINISTRATION

PART I

THE ROAD

The Road includes not only construction above the subsoil, but also the subsoil itself.

Its *life* depends on the stability of the surfacing, the foundation and the subsoil; when the last two fail, complete resurfacing is necessary.

A new road science of soil stabilization has developed in which the constituents of the soil have been minutely studied and the fundamental importance of their nature and size of grain, and the proportion of water present or required have been recognized ⁵⁸⁸. Compaction by sheeps-foot and smooth rollers, spray tanks supplying water accurately at predetermined rates, mix-in-place machinery (which can be made alternately to act as 'dry-in-place'), all contribute to the required stabilization. Plant for this purpose, notably the Barber-Greene plant, has been developed for big-scale work in America, and is highly elaborate.

The matter is one of considerable complexity. This is well exemplified in the close study of one important factor only—clay; a study which ramifies into several sciences ⁵⁹⁴. For a simple and readable summary, see ⁵⁹⁶.

The wearing surface may require complete renewal either because the cost of repair has become excessive, or because of general unevenness and discomfort. It is now possible in many cases to extend the life of a wearing surface to an almost unlimited degree by periodic surface treatment.

Length of life and freedom from repair are matters of growing importance. Road construction and repair invariably involve obstruction to, and often diversion of, the free flow of traffic; and in the case of busy thoroughfares this may result in heavy losses and serious delays and inconvenience to transport and the public.

The fact that these losses are not felt directly by the highway authority and are generally spread over so many individuals that their accumulated effect is hidden, has resulted in a general failure to recognize fully their importance.

The total *cost* of the road is made up of two parts—initial and maintenance. At first sight, a low initial cost always appears attractive. It looks well in the local budget, and allows a larger road area to be dealt with for a given expenditure. It is encouraged by pressure from the Treasury and other directions towards the acceptance of the lowest tender (q.v.), which has been obtained as a result of public advertisement.

Actually, a substantially higher first cost, with reduced maintenance charges and longer life, may be more economical in the end. The real measure of combined efficiency and economy, which is the prime aim in road making, is to produce the best road that can be built and maintained for the lowest *total* cost, having regard to the conditions to which it will be subjected. Other important factors, such as vibration, noise, and slipperiness, must also be considered.

It is erroneous to calculate the probable cost of a road upon the basis of

$$\frac{\text{initial cost}}{\text{estimated years of life}}$$

as is sometimes done. It is more accurate to take

$$\frac{\text{initial cost} + \text{estimated cost of maintenance during estimated life}}{\text{estimated years of life}}$$

dealing separately with foundation and surfacing where the life of the former is likely to cover two or more complete life periods of the latter. As the surfacing must be destroyed when the foundation is re-laid, it is obvious that any additional life of foundation which substantially falls short of a full life period of the surfacing is of little or no value.

Often it is difficult to determine the exact point at which cost of maintenance justifies reconstruction on economic grounds. The necessity to reconstruct, however, more generally arises as a result of the unsatisfactory condition of the surface for traffic, whether resulting from recognized ills or from some local catastrophic destruction, than because of excessive cost of maintenance. Where, however, the cost of maintenance does appear to be excessive, but in other respects a road is reasonably satisfactory, it may be assumed that when the annual cost of maintenance exceeds appreciably

$$\frac{\text{initial cost} + \text{ascertained cost of maintenance to date}}{\text{years of life to date}}$$

the question of reconstruction calls for careful consideration.

Agitation in favour of motorways has continuously increased since the *autostrade* were first seen in Italy on the occasion of the visit of the

International Road Congress to Milan in 1926, with a further stimulus after an inspection of the German *autobahnen* a few years later. The urgent insistence in this country is based on the immediate need for a diminution of road casualties through separation of fast long-distance traffic and the provision of roads for the *exclusive* use of commercial and private cars travelling at speed. One of the many and obvious advantages of such motorways is that they would save expensive tinkering with existing roads with less likelihood of road amenities being destroyed ⁵²⁵.

The operation of the *Restriction of Ribbon Development Act, 1935*, has had far-reaching effects upon highway development and design.

Highway authorities may resolve to adopt, in respect of any road under their control, any of the standard widths, from 60 ft. to 160 ft., included in the First Schedule of the Act. After approval of the resolution by the Minister and the advertising of such approval, it becomes unlawful without the sanction of the highway authority to provide any means of access to or from the road, or to erect any building or make any permanent excavation, or to construct any works upon land nearer to the middle of the road (as defined by the Act) than a distance equal to one-half the standard width adopted. Before, however, the resolution is submitted to the Minister, for approval, notice of the passing of the resolution of it must be given, by advertisement and, individually, to persons interested in the land affected, and an opportunity for the inspection of plans showing the standard width proposed. The Minister is under obligation to consider any objections received within a prescribed time, and, unless he considers it unnecessary to do so, he shall hold a local inquiry.

The Minister is given power to make regulations prescribing other standard widths.

Sec. 2 of the Act renders it unlawful in respect of any roads which were classified roads on May 17th, 1935, without consent of the highway authority, to provide any means of access, or to construct any building upon land within 220 ft. from the middle of the road, and, subject to the approval of the Minister, these restrictions may be applied to unclassified roads.

Certain buildings, such as a building other than a dwelling-house, to be used for the purposes of agriculture, are exempted from the foregoing restrictions.

In giving, or withholding, any consent under Sec. 2, the highway authority must act reasonably, and shall consult the planning authorities and have regard to the need for preserving the amenities of the locality and for securing well-planned development. An applicant for consent is given the right of appeal to the Minister, who,

before determining the appeal, must hold a public local inquiry, if required to do so by either party.

Sec. 13 empowers a highway authority to acquire any land within 220 yd. of the middle of the road, which is required for road improvement, and, by agreement, which they consider it desirable to acquire for preserving amenities. The Act confers upon local authorities certain powers in relation to the provision of parking places, and to require the provision of means of entrance and egress as a condition of the approval of building plans. Restriction of access to the more important roads of the country now follows more closely railway practice.

The policy of different highway authorities in operating these powers varies to some extent in detail, but generally the restrictions are strictly enforced.

Having regard, however, to the changes which have taken place, in recent years, in the alignment and standards of major road construction, the tendency of highway authorities is to proceed under Sec. 2 of the Act rather than to lay down standard widths as authorized by Sec. 1.

It is usual to allow access to houses where the area of site is not less than five acres, but where the area is less than this, but at least two acres, to attach conditions requiring the provision of suitable parking bays so that it may not be necessary for vehicles serving the premises to stand upon the highway.

Building development of a more dense character is confined to the neighbourhood of existing towns or villages, unless special circumstances justify a departure from this rule. The frontage of buildings upon classified roads is discouraged. Where development adjoining such roads is likely to involve the payment of heavy compensation or there are other good reasons for permitting development, an almost invariable condition is that an ancillary road shall be provided, so that access to the classified road may be confined to one point.

Except in respect of unclassified roads to which the provisions of Sec. 2 (1) have been applied, development adjoining these roads is much less restricted, the only conditions required being such as may be necessary reasonably to conserve amenities and to avoid obstructions to any future road widening. So far as practicable the provision of new points of access is avoided by utilizing any available existing means of access.

Similar principles apply, generally, to development adjoining Trunk Roads, but the sanction of the Minister is required. In most counties there is now a system in operation which provides for close and automatic co-operation with planning and other interested authori-

ties in regard to highway and building development, and which reduces, so far as practicable, the time required, to deal with applications under the Act. There has been given increasing and anxious attention to the further development and extension of our roads, but until there is some evidence of agreement by the Government with the copious and vigorously expressed views and wishes of the technical public, there is little advantage in discussing the matter in these pages (see especially ⁵⁴⁶).

‘ Riding ’ Qualities of Roads.

This aspect of road construction and maintenance is of great importance and it is very largely by the degree in which a road affords smooth and comfortable riding that it will be judged by the public.

Great care, therefore, should be exercised in the finishing stage of road construction to prevent waviness or unevenness of surface, materials that are rolled being particularly liable to the former defect. Various devices have been tried with the object of mitigating this trouble, including three-wheeled rollers and cross-rolling. The latter is of some assistance, but is practicable only on wide roads. To be effective cross-rolling should be done simultaneously with the longitudinal rolling, as it is of little use after the material has been consolidated. The action of the roller is, in a greater or less degree, to push the materials forward until the resistance of the material is sufficient to cause the roller to pass over it. This process is repeated at intervals depending upon the character of the material and of the roller. As a result waves are formed, although they may be too small to see or to measure. It is probable also that there is some very small increase in density of the material at the crest of the wave. However slight these defects may be, they undoubtedly encourage the formation of corrugations under traffic, but the degree in which this develops will depend upon the character of the material, and traffic, and to some extent upon climatic conditions.

Compressed rock asphalt, which is a hand-laid material and comparatively unyielding, is almost, if not entirely, free from waves or corrugations. This cannot always be said of mastic asphalt, also hand-laid, but here again the initial cause is often attributable to the method of laying. The asphalt is usually brought from the cookers in buckets and dumped in front of the men who are laying. Frequently they merely pull down the heap without moving the whole of the material, the result being that the unmoved portion—the centre of the heap—is more dense than the surrounding material. This defect occurs also with other types of materials which are spread where they are dumped, including rolled asphalt, tarmacadam, and concrete. The best practice

is to specify that all materials, whether hand-laid or rolled, shall first be dumped upon a metal plate and spread from that.

Rough riding may also be caused by the rolling up of surface dressings. This can be avoided by refraining from applying a new dressing until the old dressings have worn off or at any rate become very thin. The building up of thick coats of dressing by the too-frequent application of a new coat, whether required or not, will sooner or later give rise to this trouble; and it is, moreover, uneconomic. This applies particularly to gradients where the defect is often much more pronounced upon the down grade than the up grade. When the trouble occurs, it is useless to re-dress the surface until the wavy material has been removed, which can generally be done most conveniently by means of hot shovels.

Concrete roads are often very unpleasant for riding as a result of the joint difficulties (q.v.).

Uneven wear will cause rough riding on all types of road, and in some cases it may be desirable to sacrifice something in the way of life to secure even wear.

The early hard-wood paving blocks were an outstanding example of this. Some woods had lasting qualities of a high order, but the wear was of such a character that within a few years they became most uncomfortable to travel over.

Depressions caused by road openings are another fruitful cause of discomfort.

Ripples and Waves.

The most immediate cause of bad 'riding' qualities of a road are ripples and particularly waves in the surfacing, defects which are intimately connected with shock and vibration.

Ripples are the outward sign of unequal consolidation of the material, whether originating from unequal spreading of the loose material or from jerky rolling or irregular tamping: they are the result of imperfect technique, and for this reason, as well as for the purpose of determining the amount of wear, some countries take graphical or plaster-cast records of surface unevenness.

Incipient or potential rippling can be reduced, when practicable, by rolling across the road as well as along it.

Ripples, which are often nullified by the ironing action of traffic, may prove to be seriously detrimental as constituting the origin of waves. The cause of the formation of *waves*, which is still being discussed in technical quarters, was described and demonstrated by Dr. Vaughan Cornish, as far back as 1914, in his book on the subject. He showed that, whether the substance be slate, snow, or wet sand,

horizontal movement leading to consolidation gave rise to the formation of waves by the action of the moving body jamming the material together into a hardened mass, overriding this first obstacle and at once beginning to form another by further consolidation. His results can be applied simply and clearly to the waves produced in asphalt and tarmacadam, at the same time having regard to the action of power wheels of a car both compressing and tearing the surface (see also ³⁷⁰). *Corrugations* may be considered as being waves of a pronounced type. The matter has been examined closely by Masson and Lassailly ⁵²². The main condition is the use of a too soft binder.

The study of the character and change in road surfaces over long periods is not seriously made in this country, except in connection with particular courses of research. A considerable amount of useful information is being lost—how much a new surfacing becomes smooth through what kind and amount of traffic; the comparison between

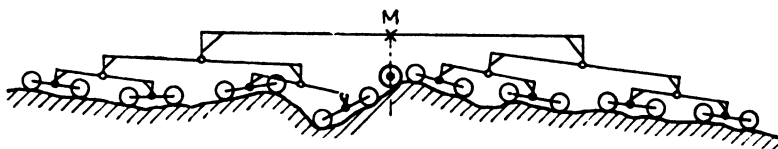


FIG. I.1.—An exaggerated example of the manner in which a sufficiently accurate level is preserved for recording at M inaccuracies in a road surface.

the changes of various types of surfacings under the same traffic; and much other information could be permanently preserved to aid the surveyor to judge the good he gets out of his work.

Records of such unevennesses can be made according to two principles: (a) the tracing of the outline of the surface on a strip of paper; and (b) integration of the bumps of a travelling car by means of a dynamometer or adding machine ^{70, 71, 73, 113, 156, 227, 260, 354}.

Various methods have been worked out.

A Swedish instrument of the sledge type counts the number of unevennesses in a certain length and sorts them out according to size ⁵⁷². But the fundamental difficulty in studying surface irregularities by profilometer is the establishment of a datum line, as it is self-contradictory to use the surface as its own datum. This has been accomplished by the mounting of the recording apparatus on a carriage borne by many wheels (16 in this country) connected together so as to preserve an accurate level over an appreciable distance. This has been done in Great Britain (Road Research Laboratory) ¹⁹⁰, America (Bureau of Public Roads), France (Viagraphpe) (Fig. I.1), and Italy (Odographo, Istituto Sperimentale Stradale, Milan).

The other type consists in measuring the amount of movement of the wheel or trailer relative to the body of a car, and connected with the speed of travel ⁵⁷³.

A British instrument ⁵⁰ uses this principle by recording, in its passage over a surface, the number of impacts as compared with standard impacts on a standard surface ; it sums the smaller impacts until they reach the magnitude of the standard, and registers over-large impacts as several standard impacts (see specially ⁵⁵⁰).

In the case of bituminous roads, the dark-coloured material absorbs more heat than it would if it were light, so that the action of the sun may be greater than is at once obvious. Some measurements (taken in Germany ³¹⁸) showed :

Air Temperature. °C.	Paving.	Temperatures. °C.	at depth of
32-33	Compressed asphalt	45-52	25 mm.
36	Wood paving	50-60	according to depth
25.5	Chipping mastic	39.5	20 mm.

Obviously, one factor in wave formation could be eliminated by prevention of movement by means of an efficient interlock of the surfacing to the foundation. For this purpose, in the case of concrete, the surface can be roughened or grooved to form a key, but no doubt a true union would be more effective. In order to prove this (but not as a commercial process), the surface of a concrete foundation was painted with a solution of asphaltic bitumen in carbon disulphide, and the solvent was subsequently burned off. On this was laid a compressed asphalt coat which was found to adhere tightly to the foundation.

The formation of 'pseudo-waves' in *wood-block* surfacing is quite different in origin. It results from the blocks swelling, by contact with excess of water, in an area restricted by other blocks and the kerb. Wave formation in *concrete* roads is somewhat obscure, and is dealt with in that section.

Bearing Capacity. The bearing capacity of a road surface depends partly on its own stability under static, rolling, and power-rolling forces, and partly on the strength of the foundation or of the subsoil (when there is no foundation).

In the case of concrete, success under traffic depends largely on its own intrinsic strength. Cases are known where vibration has led to the formation of a cavern which has been bridged, for some time, by the unsupported concrete.

Methods of calculation that are available for ascertaining the strength of concrete are considered to be satisfactory. But flexible

surfacing of the bituminous type, laid on subsoil which also possesses some degree of 'give,' have to be examined more empirically, and a large-scale indentation test has been suggested in America, by the long and well-known Prevost Hubbard. This is based on an assumed load of 12,000 lb. on 13 sq. in. of tyre surface. Although this area is elliptical, circular testing heads of areas, 5.8, 13.0, and 58.0 sq. in. are used in ascertaining the pressure required to produce 0.5 in. deflection ⁵⁴¹.

Tractive Resistance is made up of rolling resistance (concerned with the working of the vehicle, tyre reaction, irregularity of the road), air resistance (which can be 60 per cent. or over of the total resistance at 60 m.p.h.), and impact resistance (due to roughness of the road); and these can be subdivided. Measurements particularly concerned with road surfacings are confused by interference by other factors; and even the obvious use of the dynamometer is untrustworthy ⁵⁹⁷.

Shock and Vibration.

The roads of the countries of the world are being constructed to carry increased traffic loads at higher speeds. When this has not been done with care there is risk of excessive vibration, causing great inconvenience and expense to householders, and grave apprehension to those in charge of important buildings and national memorials near busy thoroughfares. It also causes great discomfort to motorists and strain on their cars.

The *origin* of shock and vibration lies in the reaction between the road surface and travelling vehicles. It results from: (1) the bumping motion of vehicles (assuming that the design, construction, and condition is blameless, which certainly is not always the case), which depends on their nature, loading, speed of travel, and state of tyres ⁷²; (2) the vibration of the internal combustion engine, communicated to the road through the chassis and wheels; (3) imperfectly set tramway rails and points, and corrugations of the rails (see ³⁷²). A vibrograph record due to a car passing over a pothole is seen in Figs I.2 and I.3. This is a well-known record, but it retains its significance.

A motor-bus (American), running over natural obstacles, was found to develop stresses on the road amounting to $2\frac{1}{2}$ to 3 times the static wheel load in the case of dual high-pressure pneumatic tyres; about twice that static load with dual balloon tyres, and slightly less in the case of single balloon tyres ⁷⁵. A comparison (also American) between the reaction on the road of 6-wheel and 4-wheel lorries has been summarized ²¹² in the following terms:

Maximum stress caused by a lorry with two rear axles spaced not

less than 40 in., is no greater than that produced by a single rear-axle load to the maximum load on either of the two axles. Effect of impact of a 6-wheel lorry is not so great as that caused by a 4-wheel lorry provided that the individual loads do not exceed the rear-axle load of the 4-wheel lorry.

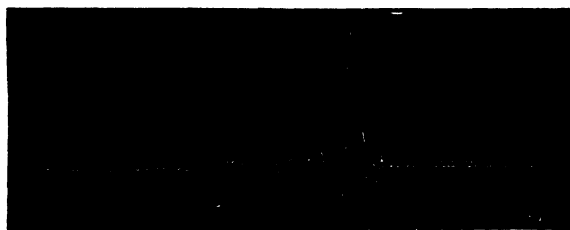


FIG. I.2.



FIG. I.3.

Vertical road movement due to a motor-car passing over a pothole at 20 m.p.h. with (Fig. I.2) solid tyres, and (Fig. I.3) pneumatic tyres. (> approx. 150.)

Sudden stresses in roads are not caused only by travelling vehicles. When a motor vehicle starts from rest, the vertical 'kick' may be considerable. According to the type of vehicle, this may vary from 4 to 23 per cent. of the load on the back axle, and the following are examples :

Type.	Rear Axle Weight in lb.	Downward ' Kick ' : % of Rear Axle Weight.
Light Passenger Vehicles	1,700	6.4
Taxicabs	1,900	5.3
Lorries (total wt. 22,000)	13,000	18.2

This downward 'kick' of the rear wheels may reach $\frac{1}{4}$ ton for passenger cars and $\frac{1}{2}$ ton for heavy lorries, depending on the load and body characteristics of the vehicle and the idiosyncrasies of the driver ⁷⁴.

This highly important matter cannot be further discussed here : it has been introduced to indicate the nature of the cause of vibration in road surfaces, and also to show that common-sense ideas on these matters are not always correct.

Vibrations that are set up spread in three directions within the road surfacing. They are examined by methods along the lines employed in seismic research, and much attention has been paid by the National Physical Laboratory to the production of instruments that will include the higher vibrations ²¹⁹, ²²⁰, and, in addition, of a method to transform axle acceleration into measurable electric forces.

Some doubt has been thrown on the technical trustworthiness of the results obtained by seismographic methods ¹⁸⁶, on the grounds that they are obtained at a point of movement which does not represent the forces active along the track of the vehicle ; that there may be phase displacement between the components in the three directions ; that there may be alteration of the road vibrations by the vibrations of the seismograph pendulum ; and even that resonance phenomena are possible. Much work has been highly developed in Switzerland ; and has been carried out, also, in France and Germany, and America. Relatively little has been published in this country (but see ³⁸³), but the following records indicate their nature.

Resilient vibration insulators act by altering the frequency of the vibrations as well as by absorbing them ; sand and gravel absorb vibrations at the source by internal friction.

It has been found, also, that there is a greater absorption of shock by clinker asphalt than by granite asphalt ; but whether this is due to the presence of air or bitumen in the clinker is not clear. Furthermore, observation has shown that the addition of an asphalt carpet on top of a coarse mixture increased the absorption of vibration to such a degree that, in a particular case, a thinner layer of concrete was needed (over the chief members of a bridge).

Valuable comparative (not absolute) figures have been obtained ¹⁸⁸ which afford a flood of light on the subject :

Surfacing Material.	Absorption. %
Concrete	0
Wood blocks (4½ in.)	12.3
2-in. Asphaltic Concrete	39.1
2-in. „ „ and 1-in. Topeka	43.9
2-in. Clinker Asphalt	43.9
2-in. „ „ and 1-in. Topeka	61.1

(At this later date, 'asphaltic concrete' may be called 'coarse single coat asphalt' ; and 'Topeka' is 'a sand carpet with about 15 per cent. small chippings'—the former is coarser than the latter.)

The following comparative figures have also been published ²⁰⁷ :

	Vertical Vibrations.	Vertical and Horizontal Vibrations.
Wood and Rubber Paving (Newcastle)	2 to 1 in favour of rubber.	70% in favour of rubber.
Granite Setts and Rubber Paving (Glasgow)	3 to 1 in favour of rubber.	70-80% in favour of rubber.

A large amount of interesting fundamental work has been done on the shock absorption of various types of tyres. This is, however, outside the scope of this book, so that two examples only are given. On a rough average it is found that a solid tyre is about one-half as absorbent of shock as is a pneumatic tyre. Further : the following approximately accurate figures for vibrations set up in a road surface have been obtained for two types of tyres, pneumatic, and a 'hollow' type in which the solid tyre has recesses cut into it :

Components of Vibration.	Tyres.		
	High Pressure Pneumatic.	New 'Hollow.'	Worn 'Hollow.'
Vertical	1	2.6	3.8
Vertical and horizontal, united	1	1.7	2.5

It was found that the 'hollow' tyre became decidedly less shock-absorbing with age ; the pneumatic tyres had remained unchanged.

An important advantage of pneumatic tyres as compared with solid tyres in relation to the highway, is that the latter can become so worn or defective as to give rise to serious impact ; whereas the surface of the former, however worn, remains free from abrupt or troublesome variations. At the same time the suction of pneumatic, tyres has a detrimental effect on some roads (see also ³⁷⁰).

The *result* of vibration and waves of shock traversing all road surfacings leads towards disintegration of the surfacing by loosening its components, to the straining or collapse of the foundation, and to the settling of the subsoil. Serious effects were found in buildings adjacent to roads carrying heavy traffic, as, for example, in Oxford ³⁸⁴, where rubber roads were laid to prevent this.

A very careful investigation of the problem has been made in the

laboratory, but the results are not immediately transferable to road construction ³²³ (see also ⁵²⁴).

In *bituminous surfacings* there is a considerable degree of absorption of vibration, so that the foundation and subsoil are to that same degree protected. This type of construction absorbs mechanical disturbances, partly by the plasticity of the binding material, and partly by the cushioning effect of the innumerable tiny air spaces (voids, q.v.). But, as the surface gets older, the bituminous carpet hardens, due to these voids diminishing under traffic to a very small figure (2 per cent. and less). As a result, vibration is less absorbed, passes more readily through the mass, and tends to shake the components of the mixture apart from one another. This is counteracted, often completely, by the healing massage and pressure of passing traffic, and the road remains sound: otherwise the surfacing may break up.

In the case of *concrete* roads (q.v.) the contrary obtains. Concrete is rigid and resists impact; it is non-absorbent to vibrations, and therefore transmits them, and failure may occur from fracture caused by fatigue.

The effect of *wood* paving is simpler to understand, as such vibration as is absorbed is by the block alone. In the case of stone *setts* and *brick pavements* this is more complicated. Where a sand bed is provided this may absorb some vibration.

Rubber roadways (q.v.) are absorbent of vibration in an extraordinary degree.

The deduction to be drawn from this is that any investigation into the behaviour of vibration and shock in roads must take into account, not only the characteristics of the surfacing, but the reaction of the road *as a whole* as a protector of the subsoil and the neighbouring buildings. For this reason it is to be hoped that the rebound instrument ²⁵⁵ devised at the Ministry of Transport's Laboratory at Harmondsworth will be developed and widely used.

Slipperiness. This has been referred to in connection with the surfacings which may give trouble, but the icing of roads is a common possibility to all. Ice or compacted snow is usually melted with solutions of various chlorides—of sodium, calcium, or magnesium. Pure salt is best diluted with sand or ashes, and treatment has been summarized in the table on p. 14 ⁵⁴⁹.

It remains to consider what occurs at the point of *tyre-road contact* where the effects of all the influences tending towards skidding ⁶³ are concentrated.

The matter is far more complicated than being merely a question of the coefficients of friction of rubber on various road surfacings.

Type of Road Surfacing.	Treatment with Salt alone.	Treatment with Salt-Sand Mixtures.	
		Maximum Proportion of Salt to Sand.	Proportion of Salt to Sand for General Use.
Water-bound . . .	May be used	Any proportion may be used	Any proportion, depending on ice conditions ; normally 1 : 4 will be adequate.
Close-textured tar or bitumen-bound surfacings and surface dressings	May be used	Any proportion may be used	Any proportion, depending on ice conditions ; normally 1 : 4 will be adequate.
Open-textured tar or bitumen-bound surfacings	Use should be avoided	1 : 4 may be used regularly at 2 lb./sq. yd.	Any proportion up to 1 : 4, depending on ice conditions.
Concrete . . .	Should not be used	1 : 4 may be used occasionally at 2 lb./sq. yd. ; should not be used regularly or on new concrete	1 : 12 (1 cwt./cu. yd.) may be used regularly at 2 lb./sq. yd.

These, as given by one authority, are ³⁹ :

Rubber on rubber	0.693
Tar-treated surface, sprayed and grouted ; and tarmacadam	0.494
Bitumen, all types of asphaltic and treated surfaces	0.597
Wood blocks	0.590
Concrete	0.486

Another set of figures ²⁴⁰ gives :

Condition of Road.	Dry.	Damp.	Oily.
Compressed Asphalt	0.648	0.510	0.207
Cement Concrete	0.736	0.606	0.230
Setts	0.685	0.624	0.242
Tarmacadam	0.697	0.572	0.282
Sand Asphalt	0.718	0.516	0.300

The coefficients of friction have been found to vary from over 0.7 for rough concrete to less than 0.2 on greasy setts or wet and smooth wood blocks or asphalt. At the same time, it should be

repeated that technical advance in road surfacing is ever reducing skidding within wide limits of conditions.

The degree of slipperiness of a road—and, therefore, its converse, the degree of grip—continuously varies with the wear of the surface ; its freedom or otherwise from grease, mud, and dust ; and the degree to which water is present, as well as other less clearly definable conditions.

These are the reasons for the differences found between many series of measurements ; and, indeed, measurements of coefficients of friction determined in the laboratory may have no direct relation to road conditions, because slipperiness of the same road may vary even from hour to hour, and vehicle to vehicle.

Complaints are sometimes heard of much skidding occurring on the passage of a car from one type of surfacing to another. This in some degree may be true when a vehicle passes quickly, but it is doubtful whether skidding would occur unless the second surface were slippery at the time. There may sometimes be also a psychological cause for this.

The effect of the *pattern of the tyre tread* as compared with smooth (or badly worn) rubber is not appreciable on dry surfaces ; but on wet, smooth, or greasy surfaces there is the great advantage which results from the high pressures which are set up at the edge of the pattern when skidding begins, and from the escape of mud through the channels between the raised portions of the pattern. This advantage, however, may be diminished by the condition of the road surface and the degree of camber, but is accentuated in cars possessing two- rather than four-wheel brakes. The critical safe speed of travel is much higher for a patterned wheel than for a smooth tread. It is an offence against the law to drive a car with the treads so worn as to render it a public danger.

The effect of *area of contact* of tyres with the road surface is complicated. An increase of area of contact means an increase of area of grip between the two surfaces, but at the same time there is a lessening of degree of grip due to lessening of the pressure per square inch. In the case of pneumatic tyres this area of contact depends on the load per wheel and degree of inflation. When a tyre with a tread pattern is flattened under load, the shape of the general area of contact is elliptical and this is larger than that of actual contact which is made up of the units of pattern. This increase of area of contact may be 15–20 per cent. These relationships are shown in the table on p. 16.

Noise. The noise and increased nerve strain now associated with normal modern life, particularly in towns, led to a campaign for its

Vehicle Type.	Tyre Size. Nominal Section Width.	Contact Pressure, lb./sq. in.	' Ellipse ' Pressure, lb./sq. in.
Popular 12-15 h.p. Passenger Car	5-00	60	45
Omnibus or Heavy Commercial Vehicle	8 in. High Press	115-130	90-100
Motor Coach	8.5 in. Low Press	70-80	65
Solid-tyred Commercial Vehicle .	140 mm.	180	180

diminution. This is closely associated with vibration (q.v.), so that the best surface for absorbing vibration is also the best for minimizing noise. For this reason, notwithstanding the relatively high price of rubber blocks, this type of surfacing has been laid in cases where freedom from noise is important.

Old-time city dwellers recall the fact that when iron tyres and horse shoes rumbled and pounded over stone setts the noise of traffic was often so loud as to be almost deafening, and they express surprise at the complaints of to-day. The suggestion is offered that traffic noises of to-day are less supportable because they are now of a higher pitch and therefore more wearing to the nerves than the deeper note of yesterday, even if it were greater in volume.

Much work has been carried out in Germany on the insulation of buildings from *noise* and vibration by the use of bitumen alone or in conjunction with paper, cork, etc ²⁵⁸. A valuable summary of the whole matter is that of Ariano ²²⁹.

Scientific examination began to be possible only when instruments were invented to measure the loudness or quantity of sound. The unit usually employed is the 'decibel,' and sometimes the 'phon.' The kind of results obtained are those, for example, measured at Cambridge ⁵⁸⁷:

Quietest college court	28 decibels
Room facing street : open windows	70 "
" " " closed "	58 "

In addition :

Street noises in Paris	over 100 decibels
Pneumatic hammers	65-95 "

Weathering.

In addition to these mechanical attacks on the road, there is also the chemical and physical effect of the atmosphere, upon which relatively little work has been done. The following consideration indicates the nature of the problems awaiting the patient investigators.

Water. The possible action of water is both chemical and physical.

The *chemical* action is mainly indirect, in that it serves as a solvent for reacting substances. It has no action on bitumen ; it may dissolve such water-soluble substances as remain in road tar, without appreciable harm to the tar itself. Concrete (q.v.) is substantially unattacked. There is some slight action on granite, as is shown in 'water-bound' macadam, in which slight hydrolysis of the felspars leads to the formation of colloidal silica and soluble salts, and the former subsequently hardens and constitutes a cementitious agent. Limestone is soluble to a small extent, and much more if the water is acid.

When attack occurs through atmospheric carbon dioxide, sulphurous and sulphuric acids (from the combustion of coal) and nitric acid (during thunderstorms), chemical attack is much greater on all mineral aggregate. The relation of such solutions to asphalt is peculiar : the acid neutralizes any alkalinity that may result from the decomposition of animal matter, and thereby diminishes any possibility of breaking up by emulsification of the bitumen which is encouraged by the presence of alkalis.

The *physical* action of water is primarily associated with surface tension, in its more ordinary form of capillarity. This property enables water to penetrate minute cracks and interstices, and the more minute they are the deeper is the penetration.

In the case of bitumen mixtures, the surface tension relations of bitumen-water-stone are such that there is a tendency for water to get between the bitumen and the mineral aggregate ; so that if the adhesion of the bitumen is not good, water will increase the tendency of the surfacing to break up. Such action is seen along asphalt gutters, where water accumulates more than in the centre of the roadway.

Increased danger resulting from such capillary action is the freezing of the water that may have penetrated into the surface. The highly destructive 'ice heaves' seen in Scandinavia and the northern American Continent do not occur in this country ; but simple breaking-up of surfaces does.

A possible *mechanical* effect, that seems to have escaped discussion, is that of 'water-hammer.' If a traffic blow is given to the surface water which communicates in a continuous film to the inner layers of a road, the shock will be communicated throughout the surfacing, and disintegration of the road may be hastened.

Heat. The only possible effects are those of softening, and of repeated expansion and contraction. The latter is considered, perhaps accurately, as being one of the important causes of the cracking of

concrete. It causes concrete slabs to curl, and increase destructive attack of vehicles by causing irregular travel.

Bituminous surfaces, consisting roughly of 80-90 per cent. of mineral matter, have an expansion of approximately that of the rock itself. In this case the plastic nature of the surfacing prevents trouble from occurring. Defects from simple softening are well known (see *Ripples and Waves*), and cracking from brittleness resulting from excessive cold can occur.

If there are any chemical or physical influences acting on the surfacing these will be accelerated by a rise of temperature.

Light. Light acts on asphaltic bitumen and tar. Acceleration tests have been devised whereby the effects can be made to take place in a short time by the action of ultra-violet rays. Work has been done in America ⁸⁵ and by some private firms in this country, and very valuable results have been obtained with asphaltic bitumen and roofing mixtures where the light acts under relatively simple conditions.

Light, acting in dry air on blown Mexican bitumen, causes a rise in the proportion of asphaltenes, carbenes, and oxidation products of polymerization and condensation. In the presence of water these reactions do not take place, but there is an increase in peroxides ⁴¹⁰. The weathering of tar is found to be less in absence of 'free carbon' ⁴²⁰.

It is very doubtful whether any such tests of road asphalt and tarmacadam are of great value, on account of the continual variation of light-absorbent films covering its surface, and other changing conditions due to traffic which are less easy to state precisely.

Combined Atmospheric Action. The simple action is that of oxidation under varying conditions of moisture and actinic value of light, and is said to apply only to tar, that is, the action of light, heat, and moisture is, in result, one of oxidation.

Roadside Rests. A movement is growing, which has had a lead from the Royal Automobile Club, as a development of an idea set out by the well-known road man, W. Rees Jeffreys, Chairman of the Roads Improvement Association. It urges that areas, large or small, simple or elaborated, should be set aside, under the aegis of the Local Authority, where wayfarers can rest from their hiking, motoring, or cycling and, if they wish, to picnic. Such Rests could, if desired, take the form of Memorials.

It is as war memorials that Sir Charles Bressey has suggested that 'many new arterial roads could be set aside as memorial avenues to some branch of the services.' Sir Charles was speaking about the replanning of London to the Wayfarers' Club.

PART II

THE ROADWAY

The roadway has been devised to facilitate the passage of traffic over the earth's surface which, unprotected, would be too weak to carry it for any useful length of time, or would be otherwise unsuitable ; and to resist the effects of weather. Its development, from the tracks of primitive man to the highly specialized roads of to-day, has been well described in a number of books associated with the names of Jusserand, Hilaire Belloc, and others.

The foundation may consist of natural rock or soil, an old road, or of a particular formation designed to give especial strength.

Even after these many years, fundamental principles are still being discussed. By some it is assumed that the duty of the top course is not only to provide a wearing surface that is easily renewed, but also to contribute to bearing the weight of the traffic. Others contend that the foundation should be strong enough to sustain independently the traffic, and that it need be covered by only a relatively thin wearing carpet—in other words, the foundation is to support the load and to protect the subsoil, and the wearing course is to protect the foundation and to afford a suitable running surface for traffic.

These two points of view find their justification under different conditions ; both are trustworthy when properly applied.

Classification.

All *surfaces* may be classified into three kinds—plastic, rigid, and intermediate. The first type is able to follow the small movements of the foundation without fracture, and to protect it from shock by dissipation within its cone of percussion and from vibration by absorption : these are the bituminous forms of construction and water-bound macadam. The second type resists all shock by its own inherent strength and absorbs vibration to a relatively small degree ; it cannot respond to any movement of the subsoil without fracture, but may act as a bridge if subsidence occurs beneath it : such is concrete. The third consists of block construction, unyielding as regards its units, but generally capable of slight movement as a whole without destruction, such as wood paving.

Roads. The Ministry of Transport's *classification* of the roads of Great Britain consists of three sections : Class I, comprising the main traffic arteries, which are 'national' in character ; Class II, consisting of other traffic routes, main roads of local importance, local arteries, etc. The third includes the balance, which are 'Unclassified,' and includes streets and roads substantially of local value only, residential and shopping thoroughfares, country lanes, etc.

It will be observed that this classification has no relation to the volume or density of traffic ; in fact, Class I covers roads carrying traffic varying from less than 100 tons to more than 40,000 tons a day. Whilst, therefore, the basis of classification may be satisfactory for the purpose required by the Ministry, namely, mainly for the provision, improvement, and maintenance of means of through communication and the allocation of grants for this purpose from the national exchequer, it is of no value to the highway engineer. A further classification taking into account all important traffic factors is still urgently required (see *Traffic*).

Another classification, based on the various types of road construction, was drawn up by the International Committee, at Paris (q.v.) in 1928 ; it was reported to the Ministry of Transport and published in the technical Press. It is not, however, a suitable basis on which to plan a book, and it will, therefore, not be followed for that purpose here. This classification is the following :

DESCRIPTION

Class I. EARTH ROADS, SAND-CLAY ROADS, GRAVEL ROADS.

- A. 1. *Earth Roads*.—A carriageway composed of natural soil of adequate firmness regulated and shaped ; occasionally improved by a layer of well-mixed sand and clay.
- B. 1. *Gravel Roads*.—A carriageway composed of a layer of gravel spread on natural soil of adequate firmness, properly regulated, with or without the addition, during or after spreading, of sand or earth.

DESCRIPTION

Class II. ORDINARY WATER-BOUND ROADS.

A carriageway surfacing composed of a layer of small broken stones with a suitable binder of earth, sand or grit.

- A. 2. *Un-rolled* (traffic bound).
- B. 2. *Mechanically rolled*.

Class III. SURFACE-DRESSED WATER-BOUND ROADS.

Ordinary water-bound carriageway surfacing, on the surface of which, at a suitable time after consolidation, a simple or compound product is applied in a thin dressing in order to waterproof the carriageway and to bind together the surface (e.g. a dressing of tar, asphaltic bitumen, liquid emulsions, thin layer of sand mixed with a binder of tar, asphaltic bitumen, or asphalt).

Class IV. SILICATED WATER-BOUND ROADS.

An ordinary water-bound road of suitable materials, such as limestones, the consolidation of which is secured by means of a calcareous material and a predetermined quantity of a solution of silicate of soda.

Class V. SURFACINGS WITH A BITUMINOUS BINDER.

A layer spread on a firm natural or artificial foundation and composed of a tarry or other suitable bituminous product, mixed *or not* with stony or sandy materials and acting both by its own wearing capacity and as a binder waterproofing the carriageway.

Note.—The words 'or not' should be left out if English practice is to be expressed.

A. 5. *Grouting method.* After the layer of materials has been spread on the foundation, the binder is added.

B. 5. *Tarred or Asphaltic Macadam.*

Pre-mixed : consists in mixing the materials and the binder before spreading on the foundation.

(1) Tarred macadam, asphaltic concrete.

(2) Stone filled, tar or asphaltic surfacing.

(3) Compressed asphalt (asphaltic rock, pulverized and compressed).

Class VI. SURFACINGS WITH HYDRAULIC BINDERS.

A carriageway surfacing composed of an intimate and compact mixture of inert materials (stone, sand, etc.) into the interstitial spaces of which mixture a cementitious binder has been introduced, either as a mortar or by spreading dry and washing and brushing in with a proportion of water.

A. 6. *Grouting Method - Cement-bound Macadam.*

After the layer of materials has been spread on the foundation the binder is added.

B. 6. *Pre-mixed.* The materials and binder are mixed before spreading on the foundation.

(1) Concrete with hydraulic binder.

(2) Mortar with hydraulic binder.

DESCRIPTION

Class VII. SETTS AND BLOCKS.

Surfacings composed of single units laid by hand in courses.

A. 7. *Paving with Natural Materials.*

(1) With units of regular shape :

(a) stone ;

(b) wood.

(2) With irregularly shaped units :

(a) hard stone approximately cubical, set with staggered joints or in curved rows (mosaic) ;

(b) broken stone or pebbles embedded in a foundation.

B. 7. *Pavings of Artificial Materials.*

- (a) Brick ;
- (b) Stone, clinker or blast furnace slag ;
- (c) Gravel blocks with a bituminous or hydraulic binder ;
- (d) Asphalt ;
- (e) Metal ;
- (f) Rubber ;
- (g) Various.

Roads and Traffic. The inter-relation between these two—the type and strength of the road to carry the present or anticipated quantity and weight of traffic—is a considerable problem. Until the coming of the motor-car, water-bound macadam in the country (other than the coaching roads) was adequate, having been consolidated for many years by relatively slow vehicles drawn by horses with pounding hooves. Later, the necessity for stronger roads to carry swifter, heavier, power-driven vehicles, brought into existence concrete, asphalt, and tarmacadam.

The design of concrete roads is a highly scientific problem which is still far from complete solution. The adaptation of asphalt to the traffic to be carried is a more sensitive matter with ‘ variables ’ which are less amenable to cold mathematics—judgment takes a larger part. There are hot-rolled mixtures, cold-laid mixtures, fine-grade mixtures, and mastic, all of which must be considered in relation to intensity, speed, and weight of traffic, ease of cleaning, location in relation to exposing and flooding, and length of life required ³⁰⁴. The problems of tarmacadam are much the same.

Planning of Highways.

Although there may be some doubt as to whether, and in what degree, the design and layout of roads is covered by the title of this book, it is desirable that brief reference should be made to this subject, having regard to its connection with, and effect upon, highway administration.

The ideal road must have long life, be of low cost, non-skid, noiseless, and pleasant to look at. It must provide for the safe and convenient movement of both pedestrian and vehicular traffic, but the design of the road will vary according to existing and probable future conditions and requirements.

Unfortunately practical considerations seldom permit the attainment of the ideal. For instance, it is often impossible to satisfy the demands of the different classes of road users—pedestrians, vehicle drivers and passengers, shop-keepers, cyclists, and others, which are sometimes sharply conflicting. The best the road designer can do is to endeavour to hold the balance evenly.

Undoubtedly many of the present difficulties and dangers would disappear if road users generally would exercise reasonable care, and consideration for others ; they would certainly be diminished if new roads were properly designed and existing ones improved.

At the same time, the conditions associated with many existing roads raise problems of very great difficulty. A consideration of this aspect of the question has led to the following conclusions ⁴¹⁴ :

“ The first step towards solution of the whole problem of the design of streets and traffic requirements must be a critical analysis of the demands of the various classes of road users, and a strict assessment of them in order to determine which are legitimate and which excessive and therefore inadmissible.

In order fully to satisfy all the legitimate requirements (let alone those which are excessive and inadmissible) much general re-design of streets and layouts would be necessary, but this is financially impossible. It is therefore necessary to depend upon a process of adaptation rather than deliberate design.

Practical policy can thus be summed up as under :

The adaptation of streets to traffic requirements cannot be carried out successfully unless all streets are definitely divided into two mutually exclusive classes : (1) arterial, (2) distributive.

Attention can then be concentrated on the arterial routes, and special measures applied. The process of adaptation should have the undermentioned specific objects :

- (i) To provide against obstruction and sterilization of space by standing vehicles,
- (ii) To provide for the free flow of vehicular traffic, by
 - (a) Elimination of traffic moving on fixed rails ;
 - (b) Segregation of opposed streams of traffic by means of continuous central islands in all streets of 60 ft. or over in built-up areas, and in all roads of 40 ft. or over not fronted by business premises ;
 - (c) Sealing up the ends of the minor side streets wherever possible in order to lessen the number of intersections in arterial thoroughfares ;
 - (d) Providing at all intersections either a roundabout or automatic traffic signals, and, in the latter case, a well-splayed junction ;
 - (e) Painting traffic lanes in roads accommodating two or more lines of traffic in each direction.
- (iii) To provide for the segregation of pedestrian and vehicular traffic, as under :

- (a) Footways should be fenced and pedestrian crossing only permitted at defined points under the protection of the traffic lights ;
- (b) Central islands should be provided at appropriate intervals, if the arterial thoroughfare has a carriageway of *less than* 60 ft. [Mistake for *over* 60 ft. Authors.]
- (c) Refuges should also be provided at the mouth of all by-streets in order to canalize the traffic as well as helping the pedestrians.

In the case of distributive roads, the same considerations apply in the matter of refuges. In all roads it is important to provide a reliable non-skidding road surface without undue camber towards the kerb.

In this whole matter an appeal is for law and order. In other words, sound principles should be established and strict adherence to them demanded. All small schemes should subserve and contribute towards the greater. Design must, furthermore, be directed towards eliminating the necessity for perpetual prosecutions with their irritant and estranging influence ; and finally, and most important of all, design must and can make a most decisive contribution towards the reduction of street casualties."

These fundamental principles of over ten years ago have had confirmation and development in the *Memorandum on the Layout and Construction of Roads* of the Ministry of Transport, 1943 ; also *Wartime Road Note*, No. 5, 1942 ; also *Design and Layout of Roads in Built-up Areas* ⁵⁶⁹, 1946.

The process outlined above must be gradual, and in many cases will be found impossible of complete attainment. Many existing arterial roads are comparatively narrow, business thoroughfares can be improved only by demolishing properties of very great value ; new roads must be built. The fencing of footpaths and provision of central refuges, for instance, would be impracticable in such thoroughfares, in fact with the exception of (i), (ii) (d), and in some cases of (ii) (a) and (iii) (c), the proposals could not be carried immediately into effect. High Street, Putney, may be mentioned as typical of this class of road. Having a carriageway of about 30 ft. and with shops on either side, it forms a link in one of the most important metropolitan radial roads. The footpaths are narrow and for several hours a day are packed with pedestrians. So far as practicable vehicles are prevented from standing in this road, but the exercise of the right to load or unload goods from vehicles causes considerable obstruction. It is a remarkable fact, however, that notwithstanding these adverse

conditions the flow of traffic is seldom impeded to a serious extent, although there is ample reason for improvement if this were practicable.

The stationary vehicle is a serious problem. This is generally either (a) a vehicle delivering or loading goods, (b) a passenger-carrying vehicle taking up or setting down, or (c) a private vehicle awaiting the return of driver or passenger. The claims of the interests involved cannot be ignored, and reasonable provision should be made for them. Practically all vehicles are used with a definite object, involving the stopping of the vehicle at certain points on the highway, and the right to stop is as important as the right to travel.

Where it is possible to prevent residential or business premises from having direct access to a main road, vehicles (a) and (c) would seldom have reason for stopping thereon, and the stopping of vehicles (b) could be so regulated as to minimize obstruction. Where this is not possible, it is important that provision should be made in the width of carriageway to accommodate standing vehicles, either throughout its length or at intervals. This is of particular importance in all shopping thoroughfares, and although much can be done to avoid congestion by providing—when practicable—ample parking accommodation in the vicinity, it is almost impossible to prevent the loading and unloading of goods, and dropping and picking up of passengers.

It should be possible in some cases to arrange with the owners of premises about to be erected to give up sufficient space for addition to the highway to provide accommodation for stationary vehicles on the understanding that the space may be used for this purpose. It is possible that in some cases at least it might be of advantage to construct a road of less width, and with part of the money thereby saved, to provide parking places off the road.

The practice followed generally in this country when designing new arterial roads, across open land is to secure a width sufficient not only for present requirements, but also for future needs. This is usually at least 100 ft. between fences, but where provision is to be made for service roads on each side parallel to the main traffic route the width should be not less than 120 ft. Where possible a strip of land on either side should be provided clear of carriageway for a paved footpath accommodating under it mains and other underground works. Fig. II.1 shows such a road—Western Avenue, Middlesex.

In some cases the highway authority has acquired an additional strip of land on either side with the object of (a) securing control of the road frontage development and (b) retaining to some extent the increased value conferred upon the land as a result of the construction of the road.

Although there has been some difference of opinion as to relative



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FIG. II.1—Example of good Road Design, Western Avenue, Middlesex.

advantages of single and double carriageways, there is to-day agreement in favour of the latter.

The main argument advanced in support of the former is, on the one hand, that the road width is more fully utilized, particularly at times when the flow in one direction is much greater than in the other. It is also argued that on double roads vehicles tend to keep to the centre and thus—in the case of a road not exceeding 20 ft.—to reduce it to a single-lane capacity. On the other hand, safety is of prime importance and the segregation of opposed streams of traffic by double carriageways undoubtedly adds substantially to the safety of both vehicular and pedestrian traffic. It is doubtful whether traffic capacity is appreciably less on a double road than on a single road of corresponding effective width. Any reduction in nominal vehicle capacity is probably compensated for by a higher standard of traffic discipline, reduction of inconvenience from headlight glare and other advantages.

In the opinion of the authors a width of 45 ft. containing two 20-ft. carriageways and a centre dividing strip of 5 ft. is preferable in many respects to a single carriageway of 50 ft.

The safety and convenience of traffic may often be increased by the provision of traffic lines on single roads.

The planning of a new road involves the consideration of many factors. Not only must provision be made for existing traffic requirements, but an endeavour must be made to forecast and provide for future changes and developments, and to make it easy for these to be accommodated with a minimum of additional expenditure.

In some cases it is not difficult to determine with reasonable certainty whether a road will ultimately be called upon to carry through traffic or whether it will remain a residential thoroughfare with little or no heavy traffic. In others there will be a substantial element of doubt, and it is then that particular care must be taken to make full provision for possible future requirements.

In determining these matters regard must be had to the character of the locality, and the probable trend and extent of future development. It is obvious that the considerations governing the planning of a new road will vary to a substantial degree with its character, and our present difficulties arise largely from failure to observe this rule. For instance, the last thing that should be allowed on an arterial road is that it should become a shopping street, but it is just such roads which, in populated areas, have developed into the busiest centres of retail trading.

In order that roads, the main purpose of which is to provide for through traffic, should, so far as practicable, be kept clear of stationary vehicles, neither private residences nor business premises should abut

directly upon such roads, and entering roads should be as few as practicable.

Two important and valuable publications recently issued by the Ministry of Transport deal in a practical manner with the lay-out and construction of roads. The first is the *Memorandum, No. 575* on the Lay-out and Construction of Roads, first published in 1943 and reprinted 1946, which is intended to apply mainly "to highways in the open country, and those portions of urban areas where building development has not imposed serious restrictions upon road-planning." The second is a Report by a Committee set up by the Minister of War Transport whose reference was, "To consider the design and lay-out more appropriate to various types of roads in built-up areas, with due regard to safety, the free flow of road traffic, economy and the requirements of town planning, and to make recommendations."

The report covers, in detail, every aspect of the matters included in the terms of reference, including road amenities, and is well illustrated.

The first-mentioned publication recommends varying minimum effective widths for roads from 60 ft. for a single carriageway to 120 ft. to include dual carriageways, each of three traffic lanes, with footpaths and cycle tracks.

In practice it appears likely that adoption of these desirable widths to a great extent will be restricted to the unbuilt or sparsely built areas of towns and to by-pass roads and roads in undeveloped country, as even a 60-ft. road will require some 10 acres of land and one of 120 ft. about 20 acres, exclusive of any necessary embankments, cuttings, etc.

It is recommended that super-elevation at curves should vary from $\frac{1}{40}$ to $\frac{1}{8}$ where the radius is from 5,000 to 7,500 ft., to $\frac{1}{14}$ where the radius is 1,200 ft. or less, and that, generally, a gradient of $\frac{1}{30}$ should be regarded as the maximum. White lines should be provided where it is not practicable to arrange the levels of a single carriageway so that the driver of a vehicle is able to see the top of any object not less than 3 ft. 9 in. high he is approaching, at all distances up to 1,000 ft. On dual carriageways this distance may be reduced to 500 ft.

Detailed recommendations are made in regard to visibility at bends ; the marking of traffic lines ; the layout of junctions ; pedestrian crossings ; dual carriageways ; parking-places ; service roads, and other matters.

The section dealing with construction refers to foundation work ; surface treatment ; camber ; footpaths ; kerbing and drainage ; and is followed by recommendations relative to grass verges ; the planting of trees and shrubs, fencing and guard-rails, and the siting of underground mains and services.

The report of the Departmental Committee accepts generally the

recommendations of *Memorandum 575* so far as they are applicable. It is too voluminous and detailed to be adequately summarized here, but some idea can be given of its scope. Part I is a general introduction to the subject, and a recital of the considerations to which regard must be given. Part II deals with the subject of Road Safety, including statistics relative to vehicles and accidents, and the measures which contribute to safety of vehicular and pedestrian traffic; Part III discusses Traffic Surveys, and the Growth of Traffic, and Part IV, Traffic Components. The title of Part V is *The Road Pattern*, and in addition to general considerations it includes sections dealing with the Relation of the By-Pass to the Urban Road system, Radial Roads, Ring Roads, Shopping Streets and Arcades, Local Roads, Boulevards and Park-ways, Sub-Surface and Elevated Roads and Simple Purpose Roads. In Part VI, the road in relation to development is considered, and in this and the following Part (VII) a number of excellent photographs and drawings of various types and features of road design is included. The latter Part deals with Traffic Segregation, Service Roads, Road Intersections of various kinds, Refuges, Roundabouts, Pedestrian Crossings, Underground Services, and Road Equipment.

Part VIII is related to The Stationary Vehicle and discusses such matters as waiting time, loading and unloading, and parking, including parks for various types of vehicles. Part IX is devoted to Amenity and Part X to Legislation.

Lamp posts and other *obstructions* upon the footpath should not be placed nearer than 15 in. from the outer edge of the kerb (see also ⁴¹⁵ on *Road Surface Design*); and the bases of the lamp posts should be as small as possible, especially on narrow paths.

Camber, the slope of a road surface from its centre to the gutter, is required for the purposes of drainage, but it is always somewhat troublesome as it may aid skidding and cause discomfort in travel. It has been suggested that the surface of the road could be flat, if the surfacing of concrete or tarmacadam be so coarse and open that water should pass through it, down to a cambered concrete foundation where it could escape ⁵⁴⁰.

Super-Elevation. It is generally recognized that super-elevation of the carriageway at all parts where vehicles make an appreciable change of direction, such as curves and road junctions, is desirable both in the interests of the road user and the highway authority. To the road user it gives a higher standard of safety, increased confidence and less strain on the vehicle, and the highway authority has the advantage of reduced cost of maintenance.

The practice of placing white lines at bends, whilst it has reduced

the danger of collision, has, where the road is cambered, increased the risk of vehicles overturning or being driven off the road.

It is seldom practicable to provide super-elevation which will fully satisfy the calculated requirements for absolute safety of all classes and speeds of vehicles, particularly in towns; and it is generally undesirable that the speed of vehicles should be such as to render super-elevation necessary.

There are considerations which limit the minimum and maximum amount of super-elevation permissible under normal traffic conditions. For instance, the cross-fall required for drainage must in any event be provided, but with modern types of surfacing this may be so little as to be harmless from a traffic point of view, and can therefore generally be ignored when dealing with super-elevation. At the same time, the maximum cross-fall should not under ordinary conditions exceed 1 in 12 and in no circumstances 1 in 10.

Even the former figure may involve some risk in certain climatic conditions. It is not unusual to see the rear wheels of heavy vehicles, such as motor-buses, when pulling up on a cambered road with cross-fall of 1 in 24 or less, swerving to the near side. Moreover, a cross-fall of 1 in 12 may be very uncomfortable for horse traffic in frosty weather.

The effect of this may be seen by reference to Fig. II.2, which shows graphically the calculated cross-falls required on curves of different radii for various speeds. It will be observed for instance that, adopting the above maximum, a vehicle travelling at 15 miles per hour will—theoretically—incur some risk on a curve of less than 180 ft. radius; at 25 m.p.h. on a curve of less than 500 ft.; and at 35 m.p.h. at less than 950 ft.

Practical results can be very different from those indicated by calculations, which is particularly fortunate in this example, as otherwise most of the road curves in this country would be piled up with wreckage. The fact that day by day thousands of cars are safely negotiating thousands of bends at speeds and under conditions calculated to involve them in inevitable disaster, is evidence that there are other very important factors conducing to safety which the calculations ignore.

A super-elevation chart (which has been issued by the Ministry of Transport (Scottish Division) (not Fig. II.2) indicates a minimum cross-fall of 1 in 40, and a maximum of 1 in 12. For drainage purposes, however, it may be desirable to provide at times a somewhat sharper fall than 1 in 40, and where speeds generally exceed 20 m.p.h. there should be no objection to increasing this figure.

Generally it would appear that, in reasonably satisfactory conditions, a cross-fall corresponding to the calculated requirements of a speed of 20 m.p.h. (Fig. II.2) but subject to a minimum cross-fall

to suit drainage conditions and a maximum of approximately 1 in 12—together with other factors not included in the calculations—should take care of all classes of traffic under practically all conditions.

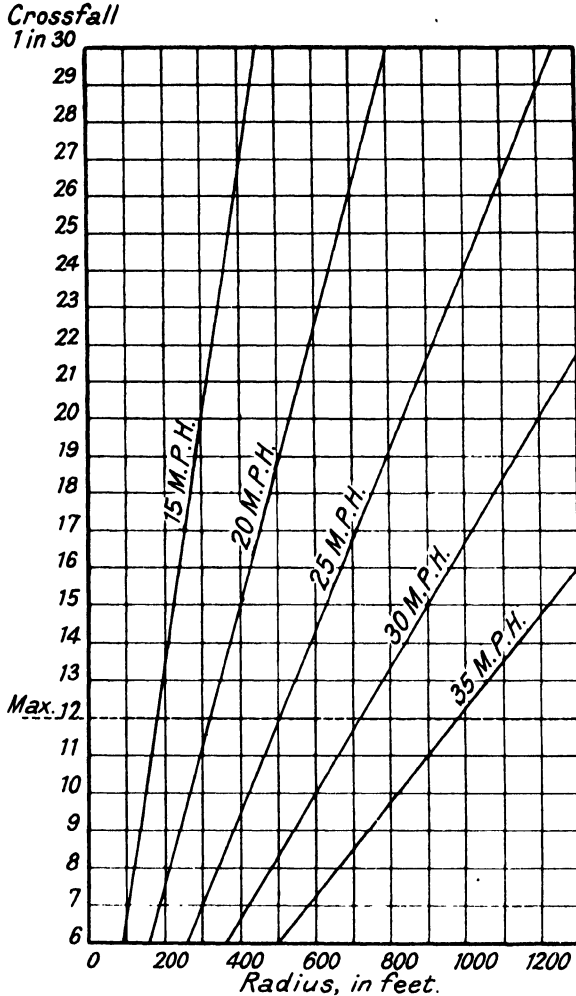


FIG. II.2.—Super-elevation Graph.

Where this ideal is difficult of attainment, however, considerably less will probably be found to be of appreciable benefit, even if it be practicable only to raise the outer half of a cambered curve to such an extent as to reverse the cross-fall. It is clear that the elaborate calculations sometimes applied to the consideration of this problem are of little practical value, but those who are interested in its

theoretical aspect will find it dealt with at considerable length in several works ^{328, 369, 370}. The matter is still being vigorously discussed at theoretical and practical levels.

To-day, wear of a road is caused by little else than motor traffic. This wear results from stresses in the surface due to the weight, power wheels, and tendency to skid being transmitted to the surfaces of contact between the tyre of the vehicle and the road surface. From the viewpoint of safety this will be discussed on p. 35, but a wider examination has been made at the Road Research Laboratory, by Markwick and Starks ⁴¹⁵, in which the normal and shearing stresses have been analysed, the latter rising to 50 lb./sq. in.

SAFETY

(Important recommendations are to be found in the *Report by the Select Committee of the House of Lords on Prevention of Road Accidents*, 1939, and the *Interim Report of the Committee on Road Safety*, Ministry of War Transport, 1944 ; *Final Report of the Committee on Road Safety*, Ministry of Transport, 1947.)

"I do not without danger walk the streets," said Antonio in Illyria, in the early days of the seventeenth century (*Twelfth Night*, iii, 3), and the same is being said over two and a quarter centuries later with increasing bitterness.

An enormous amount has been published, giving facts and suggestions, in newspapers, societies, and pamphlets. Enough is known for the application of this knowledge to develop.

A solution is sought of this most complicated matter. Statistics cannot be interpreted without most careful and wary examination and dissection. Human beings cannot be fully controlled on account of their fundamental human characteristics. Roads cannot be made safe by resurfacing without (in many cases) replanning. Cars cannot be made innocuous by correction of errors of condition only. Each line of attack is intimately connected with the others, so that it seems that a solution is only possible by a vigorous advance of front rather than the formation of a series of isolated salients.

For some time past the Pedestrians' Association has been pressing its vigorous anti-speed proposals ; the road section of the Royal Society for the Prevention of Accidents (formerly the 'Safety First' League) has for years been advocating care on the roads through statistics and analyses, warnings, posters, and pamphlets. But the conscience of the Public and the Government, both extraordinarily slow to be moved more than superficially, at last seems to be aroused, and towards the end of 1945 they both gained in aggressiveness.

A popular newspaper ⁴⁶⁶ started a league for road-sense amongst children ; the police helped children across the road opposite their school entrances ; the B.B.C. held talks with adults and with children ; the Nuffield Organization contributed to child education ; a women's clothiers arranged an exhibition specially aimed at peace-time road problems for children ; the Royal Automobile Club put forward 15 points of great practical wisdom ; the Ministry of (War) Transport embarked on a £250,000 campaign as part of which its Road Safety Committee designed big posters and harrowed one's feelings in the Press ; and a new edition of the *Highway Code* was issued.

The history of this valuable little pamphlet is interesting. Two years before the Boscowen Royal Commission on road safety, Lieut.-Col. Mervyn O'Gorman put the idea of such a publication before the Committee of the Royal Automobile Club, which offered it to the Ministry of Transport of the day. It was refused on the grounds that it was impossible for a government department to produce a code of behaviour, the infringement of which could not be punished ; in particular the proposed code advocated walking on the left of the pavement so as to face the oncoming road traffic. Later, O'Gorman represented the R.A.C. before the Royal Commission when giving evidence on its behalf and the Code ultimately had its place among the recommendations made to the Ministry. This route led to its publication (in 1935) as an official document—with the omission of insistence on left-hand walking !—but with the substitution by the curiously reversed phrase : “ On a pavement or footpath do not walk alongside the kerb in the same direction as the nearer stream of traffic.”

It is horrifying to think of the number of casualties which have occurred owing to neglect by the Public of the simple and wise advice in that small pamphlet. The necessity for such uniform left-hand walking is ever more urgent ; and this is emphasized in the new edition of the *Highway Code* allegedly sent to every householder in this country.

There has been a long and justifiable clamour about the money taken from motorists as car tax and petrol tax being diverted, in considerable proportion, from its originally promised purpose of road upkeep and improvement, to the Treasury's general account. If this money had been spent as at first intended and promised, immeasurable tragedy and misery would never have happened.

The number of casualties on the roads of this country has long been dreadful. This has been most earnestly considered by the Ministry of Transport and by the General Public, but the numbers have varied only slightly. Broadly, the Ministry blamed the carelessness of the road users (the vehicular traffic and the pedestrians), and each section of road users blamed one another and all blamed the

motorist: both are mainly unjustified, and only recently is much blame being attached to the design of the road (see also ^{101, 423}).

The speed of the motor-car is not the main factor, as only $4\frac{1}{2}$ per cent. of accidents occur at a speed of over 20 m.p.h., but congestion probably is, and here is the crux of the matter. The imposition of a 20 m.p.h. speed limit during the black-out has not led to improvement ⁴¹⁰; indeed, official figures show a greater number of deaths on 'restricted' than on 'de-restricted' roads.

At the same time, the responsibility on the users of the footpath is great, not only the pedestrian but also the playing children.

Many constructive suggestions have been put forward: the provision of motorways and of country footpaths and cycleways; the complete separation of up and down traffic; the improved design of road intersection ⁴¹⁶; the banking of bends; fining—but with right of appeal—on the spot; testing of driving efficiency before the issue of a licence; improvement in the design and control of cars; reward or recognition for good driving; better control of the pedestrian and cyclist; education of all road users of sensible behaviour; escorting of schoolchildren across roads by policemen. Many of these have been carried out, and the result has been disappointing.

It has not been sufficiently recognized that the problem of road safety involves a short- and a long-term policy; also that it must be solved independently of the active awareness of the road user—you cannot set the mind to watch the mind.

The short-term policy is through punishment (the least effective), the control of traffic by lights and police, control of pedestrians by crossing-places and guard-rails, the provision of non-skid road surfacings, and by admonitions—which are admired for their wisdom and soon forgotten.

The long-term policy consists in educating adults and children; and adequate illumination of the road in the day, night, and fog; but mainly the proper design of the road of such dimensions that proper vision is possible, the segregation of the various types of traffic is effected, and the movement of each unit of each type is smooth and unhindered ⁴⁶⁵ and foreseeable ⁴⁶⁷.

The problem can be solved only by a thorough examination of the subject; not by guesswork and snap judgment, but by the dissection and examination of traffic conditions by an independent scientific body, using scientific methods of thought and inquiry. This body should strive primarily "to make all traffic motion *foreseeable* by making *all* units orderly in their behaviour." This has long been advocated with great penetration and vigour by Lieut.-Col. Mervyn O'Gorman ⁴⁶⁷.

Apart from material causes of accidents, there is undoubtedly the psychological also to be considered. It is found that, in addition to the careless, selfish, and reckless driver, there is the 'accident-prone,' whose constitutional lack of suitability to road conditions renders him unknowingly a danger to the public. This matter of proneness has been deeply studied by the Industrial Health Research Board of the Medical Research Council, Report No. 84 ⁵⁵⁸. Shortly before this, attention during several years had been given to the subject by the National Institution of Industrial Psychology, and a scheme was worked out for the examination of motorists for the ten characteristics that make a good or bad driver. It was so successful that at least two insurance companies gave a rebate on their premiums to those who had passed the tests. This has lately fallen into abeyance, but may be considered again later ⁴⁶⁴.

Unbiased judgment exonerates the motorist from being the cause of every accident in which he is involved. Apart from the psychological considerations just referred to, it is interesting to examine one of his difficulties—that of vision. The motorist can be bothered by insufficient contrast between the object and its background (see also p. 44), and by the colour and reflecting capacity of the road surface. Laboratory tests with and without an artificial fog have shown that fog lowers the difference between the appearance of wet and dry surfaces; that there is a maximum strength of illumination above which visibility diminishes; that fog does not lessen colour contrast; that yellow light is somewhat disadvantageous ⁵⁵⁷.

Slipperiness. An early form, apart from icing and the like, was the lack of grip of horses' iron shoes on stone setts. The modern trouble began when the motor-car travelled at speed on the early rock asphalt surfacing, with or without the lubrication of damp or dust. The development of skid-proof roads resulted from the public outcry which arose, not only by motorists whose speed was gradually increasing, but also by horse owners who resented that the rates they paid should be used to produce surfaces that were dangerous to their animals. Criticism, not far from invective, was levelled against asphalt and tar roads (any black surfacing was 'asphalt' to some and 'tar' to others), but with no mention of the fact that other forms of paving were by no means free from the skidding danger.

The tendency of vehicles to skid on dry dust and wet leaves is probably quite unavoidable.

There exist three influences in road safety.

Firstly, there is *road construction*, dealing with the slipperiness of surface, number and position of refuges, camber and super-elevation

and their warning and illumination. Then, there is the *traffic*, with its signals and signs, and the regulation of its speed, the capacity of its drivers, and the choice of one-way and gyratory directions. (These and other matters in which the road engineer can assist in the lowering of the number of casualties have been reviewed by F. A. Rayfield ⁵⁵⁹.) Finally, there is the character and construction of the *vehicle*, and the nature of the *tyres* and *horse-shoes* at the surface of which slipping occurs.

Road Construction. The qualities of a road surface that make for slipperiness are numerous and subtle, and in the following considerations facts are associated with those theories which show a high degree of likelihood.

Asphalt Surfaces. The character of the bituminous binder has much to do with slipperiness. The harder it is, the smoother the surfacing becomes, and the less is its capacity for holding large-sized chippings through loss of stickiness on which adhesion depends. At the same time, the softer it is the more easily is it affected by rise of temperature and the greater the risk of rising to and spreading over the surface, and again tending towards sluggishness.

For a long time the underlying principle of asphalt construction was to provide a rich mixture in order to render the surfacing water-tight and thereby to prolong its life; and when the binding material 'souped up' ('fatted up') and the surface became polished and (even without the assistance of a sealing coat) effectively sealed. In cities, such a surface may be rendered still further unsafe, by the lubricating effect of oil from motor-cars, organic matter, including leaves, dust and water forming an emulsion that is not always easy to remove ². In some places the most potent of these substances is probably soot: many roads were reasonably safe at all times except when rain followed a dry spell, during which particles of soot accumulated upon the surface.

Another constructional cause of slipperiness of asphalt surfaces can be an excess of filler ³. This fine material tends to adsorb the asphaltenes more than the oily constituents, freeing the latter to make the surface slippery: this has been noticed more with compressed than with manufactured asphalt. In particular, limestone should be watched in this connection because, although its peculiar capacity for associating with asphaltic bitumen makes it a most valuable road material, an excess of limestone filler may lead to trouble. How far the character of the limestone has an important effect is not known. At the same time, a filler can diminish the slipperiness of a bituminous binding material; and it is on the presence of fine mineral matter in Trinidad Lake asphalt, of minute limestone

shells (globigerina) and their fragments in Bocton asphalt ³, and of the ' free carbon ' in tar, that the anti-skid properties of these materials are claimed.

The ' souping up ' or ' bleeding ' of bitumen in a rather rich asphalt surfacing is due to its being squeezed by contraction due to compression of the mineral aggregate. It has been suggested, also, that both bitumen and tar rise to the surface by capillary action, facilitated by rise of temperature diminishing the viscosity of the bituminous material ⁴⁰⁸.

The film of detritus that forms on the smooth asphalt surface has been investigated in Germany (and there is no reason for doubting the general applicability of the facts to England), where it was found ²³³ that 0.7-3.2 g./sq. metre was collected, of which 10-20 per cent. was water-soluble and of high nitrogen content, indicating animal albumen. Thirty to forty per cent. of the water-insoluble substances came from the road itself, and the remainder consisted of wool, leather residues, oils and bitumen, the latter holding motor exhaust gases in solution. No rubber was found. Thus, water, oil, dust, and organic matter form a film of emulsion, which is not easily washed away by hard water.

The avoidance or mitigation of slipperiness of asphalt surfaces may be attained in more than one way.

1. *At the Time of Construction.* (1) A coarse asphaltic concrete may be laid. (2) Chippings may be incorporated in the wearing surface. (3) Chippings may be rolled or pressed into the newly laid surface, at the right moment of consolidation ; but, in order not to upset the the balance of bitumen and mineral aggregate, they should be pre-coated. A nice judgment is required in order that the surface of the road shall be rough through the partial projection of the chippings—rough enough to give a grip to motor tyres without causing too great a destruction of the tread. The surface illustrated in Fig. II.3 is interesting, in that it is described by two opposing schools of thought as supporting their ideas. The one considers that the gritting is inadequate as there is too much asphalt exposed ; the other, that it is adequate, as the edge of every chip is unhindered in the grip it affords to the passing tyre, to a degree even preferable to that given by a completely ' armoured ' surface. (4) A penetration method may be used where the nature of the traffic and other conditions permit. A penetration macadam of big stone, up to 2 in. and more (the full thickness of the surfacing), is one of the features of American roads ; but the employment of such relatively large stone is a practice that has not been adopted here. Types of non-skid surfaces are seen in Figs. II.4, II.5, and II.6.

2. *Subsequent to Construction.* (1) Sharp grit may be scattered on a surface sufficiently soft to hold it. It should not be necessary to give warning that the distribution of unsuitable grit on a hard sloping asphalt road increases and does not diminish the danger of slipperiness—and yet this has been seen. Fine, soft or dirty sand should be avoided as tending to increase slipperiness. (2) Surface treatment may be given with asphaltic bitumen or tar with emulsions or cut-backs, followed by rolling in of hard grit or chippings. The mineral matter should be applied in excess, and all loose material should be brushed off after the bituminous dressing has set hard. If allowed to remain it may give rise to nuisance from dust, or by acting as an



By the courtesy of The Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. II.3.—An Asphalt Surfacing with Precoated Chippings.

abrasive between the wheels of vehicles and the road surface. At the same time it must be considered whether closely irregular or even patchy gritting would not give an even more anti-skid surface, if the chippings remained firmly adherent. The surface, however, would look unsightly. (For details, see ⁹².) Treatment can also be given with a solvent, so as to soften an existing sufficiently rich surface, before the spreading of the chippings ⁹⁶. In the case of some of the older rich mastic roads it has been found that dressings of sharp $\frac{1}{4}$ – $\frac{3}{8}$ in. grit, applied dry, are almost completely absorbed into the surface and remain effective for a considerable time.

It has been claimed for *tar construction*, that the binding material is intrinsically less slippery than asphaltic bitumen.



By the courtesy of Colas Products, Ltd.

FIG. II.4.— $\frac{3}{4}$ -in. Basalt Chipping, held by a hot bituminous mixture.



By the courtesy of Messrs. Highways Construction, Ltd.

FIG. II.5.—Type of Modern Non-skid Asphalt Surface.



By the courtesy of The Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. II.6.— $\frac{3}{4}$ -in. Precoated Chippings, as Surface Dressing.

If this claim be true, it undoubtedly results from the 'free carbon' natural to the tar. This is a filler, natural to the tar, and not only adds 'body' to it, but gives an inherent roughness. At the same time, changes take place in a tar road, such as evaporation of tar oils and naphthalene and the probable resinification of other constituents sensitive to the atmosphere, all of which tend to cause hardening; so that lack of 'give' on the outer surface may make for slipperiness. At the same time, this very hardening has been cited as a basis for the claim of non-slipperiness¹⁷⁹; and the superiority of tarred materials over asphalt through this property has been put at 18 per cent. for vehicles braking at 25 miles per hour¹⁸⁰. In addition to this, the character of its temperature-viscosity curve explains the bleeding of a tar road in hot weather, but this fault can be mitigated.

The avoidance of slipperiness is attained by much the same methods as those referred to under asphalt—the choice of correct nature and proportions of the tar and stone components, and surface treatment when required.

Concrete. One experienced motorist may assert that concrete roads are not slippery, and another the direct contrary. This may be due to actual variation of the quality and dustlessness of surface, and the condition of the car tyres.

Wood block paving often escapes comment in discussions on slipperiness; but it is common experience that, when it is wet, cars can involuntarily reverse their direction of progression on this class of paving with a facility not in accordance with some claims that are made. Proper surface treatment can do much to minimize this danger.

To-day, there is no technical reason why any road surface should be dangerous at reasonable rate of travel; and safe limits are being steadily raised by the work of the road constructor. For night traffic, the light colour of a concrete road is an advantage.

Street Refuges and Guard Posts (Bollards): Kerbs, etc. The ordinary street refuge usually serves a dual purpose: it divides two or more streams of traffic, guiding each stream into its proper channel, thereby preventing confusion and reducing danger and (as its name implies) it facilitates the safe crossing of a thoroughfare by pedestrians.

Modern conditions, whilst rendering the provision of refuges even more necessary than in the past, have in some cases had their value reduced to the pedestrian. For instance, at one time he knew that he could safely leave the kerb for the refuge if the road was clear on his right, and the refuge if the road was clear on his left. Now in one-way streets he may have to look either one way or the other, or both ways in order to feel sufficiently safe.

In towns the most useful type of refuge is generally formed of two small raised islands with an unraised passage between, provided principally for the safety of invalid chairs and perambulators (Fig. II.7).

The siting of refuges is dealt with under *Road Design*.

Refuges should be adequately lighted and, except under special conditions, should be of sufficient width to allow a clear space of at least 1 ft. 6 in. between the outside edge of the kerb and any lamp or other post, or any overhanging sign or lamp under the refuge.

This usually involves an overall width of from 4 ft. to 4 ft. 6 in. The main protection should have the form of a fairly high kerb—not less than 6 in.—but to prevent danger from vehicles mounting the refuge, guard posts are usually provided at each end. There is some difference of opinion as to whether these posts should be of sufficient

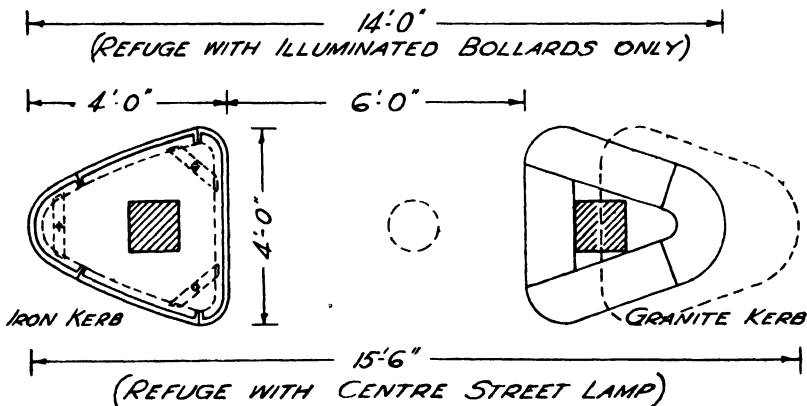


FIG. II.7.

strength to withstand, without bending or breaking, the heaviest impact likely to be received from a vehicle; or whether they should be of such a character as to yield, at any rate to an appreciable extent, before a colliding vehicle. On the one hand, it is argued that an unyielding guard post is likely to occasion serious damage to the vehicle and its occupants, and that the post should therefore act to some extent as a yielding buffer. On the other hand, it is claimed that any pedestrian on the refuge is entitled to absolute protection from vehicles. The reasonable course appears to be to reduce so far as practicable the risk to the vehicle whilst preserving the safety of the pedestrian, by providing guard posts which are likely to bend without breaking.

This was not developed. Evidence against its unsatisfactory nature (in Putney) included the shock experienced by a bulky and tired policeman, who found such a bollard slowly collapsing under him.

At one time guard posts to refuges were illuminated by gas or electricity. From one to four lighting points were provided, with a total wattage of 50 to 100. A subsidiary electric circuit was sometimes provided in case of failure of the main supply, but the practice appears to have been abandoned.

There are numerous designs of posts for this purpose, some with illuminated heads, so arranged that the light is reflected down the post, illuminating its whole surface (Fig. II.8). In most cases a 'Keep Left' sign in the head adds substantially to the value of the post.

It may be taken as evidence of the utility of illuminated guard posts that, whilst the ordinary unlighted posts are frequently damaged by colliding vehicles, illuminated posts, at any rate in London, have suffered to a negligible extent.

In Wandsworth, various experiments on illumination of posts on refuges and the omission of a centre street lamp (Figs. II.7 and II.8), showed that this renders necessary the lighting of the posts all round, but enables the refuges to be reduced in over-all length, thereby providing better accommodation for pedestrians, perambulators, etc., and saving the cost of a street lamp.

A further reason for lighting refuge posts all round is that in case one post is damaged the light from the other will be visible, but this involves the independent lighting of each post. The light from the sides of the post is of assistance to pedestrians in crossing the road, and renders them more easily seen by vehicle drivers.

The latter is of the greatest importance to public safety, and with this object various devices were tried. That finally adopted included the fitting of condensers in the heads of the bollards, the effect of which—in addition to the reflected light from the lower portions of post—is to cast a strong beam of light across the carriageway from each bollard, on each side of the refuge, and also to light up pedestrians in the act of crossing. The light is cut off at such a plane above ground level as to prevent glare to pedestrians (Fig. II.8).

In addition, the illuminated refuge posts—or bollards—designed to Wandsworth requirements, include (a) illuminated 'Keep Left' sign in the head of the post; (b) adequate watertight accommodation for the time switch, etc.; and (c) lighting by means of one 40-watt and one 60-watt lamp; (d) good accessibility for connections, lamp, changing, etc. It is most essential that the posts, as well as the general street lighting, should be lighted up in times of fog, and with this in view automatic controls of the lighting and extinguishing of the lamps in accordance with the intensity of the natural light was adopted with a good measure of success. The main objections to the system are (a) high cost and (b) failure to respond to a heavy white



(A) Gas Lighting.



(B) Electric Lighting.

Illuminated Refuge Guard Posts --Bollards, with well-lighted heads and shafts. Road surface illumination confined to small areas immediately surrounding the posts.



(C)

Left side of posts, ordinary lighting, resulting in very limited illumination of road surface and pedestrians. Right side of posts fitted with condensers, yielding strongly defined beams of light across carriageway and good illuminations of pedestrians.

FIG. II.8.

mist, when visibility may be reduced to such an extent as to render illumination of the posts advisable:

In some cases where gas and electricity are not available, *reflex lenses* or *prisms* are used. They are also fixed to guard posts; and are much used to great advantage in the country, on telegraph and other posts, by the side of the road, at the ends of bridges, and as warnings of obstructions and points of potential danger. The *painting* white and *illumination of kerbs* are also valuable aids to safety. *Guard rails* have been called for since 1935, but little was done. To-day their use is extending, in spite of some opposition in shopping streets, where vehicles might be hindered in setting down. The siting of lamp posts and pillar-boxes sometimes ignores the convenience and safety of pedestrians.

Street Lighting. The prime object is to render visible the various units of traffic on the roads. At first this resulted from the general illumination of the streets together with the lamps on the vehicles carried, primarily, to indicate their presence. As traffic became faster with the advent of the motor-car, headlamps became stronger so as to illuminate at a greater distance and give more time in which to deal with an emergency. It was found that the various objects commonly met with were shown up irregularly and imperfectly; especially in the case of pedestrians and the varying nature of their clothing. This forced a drastic reversal in the principles of road illumination; emphasis was removed from the illumination of the object on the carriageway to the illumination of the road behind it. In this way a silhouette of the object was made clear, but at the same time the difficult problem of uniform lighting of the surface without glare had to be solved. The *Final Report of the Departmental Committee on Street Lighting*, of the Ministry of Transport, 1937, should be carefully studied; it has been 'illustrated' very vividly by the British Electrical Development Association, Inc., 1938. The arrangement of lighting units is a subject of some controversy. Some advocate (a) central—suspended—lighting, others (b) lamps oppositely placed and others, the majority, (c) staggered units near the kerb line. Criticism has been levelled against the lighting by system (b) on the ground that by creating an area almost equally illuminated from both sides, pedestrians crossing the carriageway often become almost invisible. It is now generally agreed that, having regard to both effectiveness, and cost, the staggered arrangement of lighting units is usually the most satisfactory, although there are circumstances where centrally suspended, or oppositely placed, pairs of units may be adopted with advantage.

By far the most important purpose of public lighting is the pro-

vision of adequate visibility in roads and streets, in the interests of public safety. It should also serve the convenience of residents, and aid the police in the exercise of their functions; but given satisfactory visibility for safety, these, usually, will be taken care of.

Special lighting may be required in some cases, for instance, shopping centres.

From the point of view of safety, good visibility is by far the most important. The tendency in many towns to light to an extravagant extent certain main thoroughfares, and to leave the majority of roads in semi-darkness, cannot be too strongly condemned. In many cases this increases the danger rather than reduces it, because the eyes of a driver passing suddenly from a highly illuminated thoroughfare into one that is dimly lighted require an appreciable time during which to become adjusted to the changed conditions. This is a potential source of danger, apart from the inherent risk associated with inadequate lighting. There can be no doubt that a reasonable standard of lighting throughout a town, without abrupt changes, is of much greater value to the inhabitants as a whole than such a patchy system.

Bright lighting finds favour with traders as a highly illuminated thoroughfare undoubtedly attracts business; and also with the suppliers of gas and electricity, as spectacular lighting is considered to be a good advertisement for the illuminant adopted; but the safety of the community as a whole must take precedence.

The problem of illuminating street objects within certain limits of uniformity and without glare, in both dry and wet weather, is seriously complicated by the irregular and changing character of the reflection from the road surfacing, dark areas between lamps, and the effect of shop lighting, reflection from buildings, etc.

An attempt was made, as a result of observations made in Glasgow⁶⁰⁵, to arrange some twenty-six road materials in a rough scale of relative visibility, but the order of merit is changed so often and to such an extent by varying conditions that any such a scale is of little practical value.

These variables are: the colour and tone of the material, the age, amount of wear, cleanliness, character of surface treatment, irregularity of surface, degree of roughness, contiguity with other materials, degree of wetness; together with slope, camber, width and length of view, and the relationship of carriageway to the footway, and the position, height, spacing, and strength of the lighting units, and their relation to the object to be seen and the position of the observer.

Two paragraphs from the *Departmental Committee on Street*

Lighting, Ministry of Transport, Final Report, 1937, are of significance here :

“ 65. Practically every type of road surface in general use undergoes changes in its optical properties during life as a result of wear, and in many cases the changes are so marked that an installation designed to produce a good result on a surface which had been subjected to a few months' wear would be much less satisfactory in the case of an entirely new surface. With some materials there is considerable change in the surface during the first few months and thereafter there is but little change, whilst with others there is a gradual alteration which proceeds throughout the life of the surfacing. These changes in optical properties are greatest with the rougher types of asphalt and tarmacadam and with surface dressing, and least with the smoother materials and with stone setts ; concrete subjected to much traffic sometimes becomes markedly specular in its reflection characteristics, but the degree of change naturally varies. Apart from the relatively slow changes resulting from wear, periodical abrupt changes, often very marked, may occur when the road is surface dressed and also when it is re-surfaced with either the same or a different material.

66. In view of these considerations it is clearly impracticable to make any recommendations regarding the design of a lighting installation on the basis of the nature and condition of the road surface at any particular time, or to attempt to devise recommendations regarding the most satisfactory manner of lighting various types of surface. We would observe, however, that in our view those responsible for the design of installations, and in particular of directive equipment, should be encouraged to develop types of distribution which are of the most general application, i.e., most suitable for the majority of surfaces and least affected by changes in their condition, since, although if such a type were adopted generally the best possible result would not be obtained in each and every case, a fair average standard of lighting could be maintained on the roads of the country as a whole.”

From this it is seen that the phenomenon is a very complex one. A smooth or very wet surface gives specular reflection, the source of light appearing as a patch or a band, and causing glare and dazzle. A rough surface scatters the light evenly ; it is pleasant to the eyes and gives contrast with the various objects upon it. A mixed reflection is given by surfaces containing stone aggregate.

Within the limitations referred to, it may be stated that concrete has the highest reflecting power (37·5 per cent. dry and 23 per cent.

wet) and rock asphalt has the lowest (6·5 dry and 3·2 wet). Accurate figures are obtainable by direct measurements with suitable photometers ⁴⁹⁸.

Increased safety from decreased glare into the eyes of the motorist was hoped for, from using polarized light for illumination. But it was found, amongst other results, that whilst concrete gave the best reflection at least four times the intensity of the source of light was necessary ⁴⁹⁵.

The whole matter has been examined with increasing urgency for the past 15 years, and the work of J. W. Waldram ³⁶⁵ and others ^{226, 496, 497} should be studied.

The subject of street lighting gave rise to much discussion before the Second World War. A British Standard Specification No. 307 was issued in 1931 and, although, by no means perfect, it is generally agreed that it served a useful purpose. In 1934 the Minister of Transport appointed a Departmental Committee to "examine and report what steps could be taken for securing more efficient and uniform street lighting, with particular reference to the convenience and safety of traffic, with due regard to the requirements of residential and shopping areas and to make recommendations."

The Committee issued an Interim Report in September 1935 and then a Final Report in August 1937.

The reports contain recommendations in respect of a national standard of street lighting and they suggest, as a 'broad classification' of roads with regard to their lighting, two classes, A and B. In Group A—'Traffic Routes'—are included "roads on which the standard of lighting should provide an ample margin of safety for all road users, without the use of headlights on motor vehicles." In Group B—'Other Roads'—are included "all other roads which the responsible authority considers should be lighted." The Street Lighting Committee of the British Standards Institution undertook the preparation of a specification, and the work was well in hand when World War No. 2 brought about a complete black-out both of street lighting and of the activities of the Committee. Work was resumed shortly before hostilities in Europe ended; but the result was found to be more of a Code of Practice than a Specification, and it was agreed that the Institution should co-operate in an endeavour to prepare a standard specification which would not attempt to deal with aspects of the subject for which a code of practice was necessary. In 1946, the Ministry of Transport became the central authority for street lighting.

In an attempt to increase the visibility of pedestrians at road crossings, a black and white chessboard stone pathway has been tried ³⁷⁴.

In town, in addition to painting, a number of ingenious schemes have been devised to make *kerbs visible at night*. Among these is the insertion at regular intervals of an illuminated kerb-‘stone,’ which showed the existence and direction of a road edge but in a manner more expensive than that in which the lights of oncoming cars is reflected back to the driver. This successful principle has been applied by cutting variously-shaped wedge-shaped portions out of the vertical or top surface of a kerb-stone so as to leave surfaces at the correct reflecting angle ^{532, 533, 536}.

A further step has been to add reflecting lenses, and in some cases to use colour with specific significance for safety ⁵³². With regard to curves in country roads, more might be done for night drivers by a considerable extension of the practice of indicating the approach to, and the position of, curves by means of some form of reflectors set on posts. For some time concrete kerb with reflecting facets or lenses has been used with satisfactory results. The official attitude to them has been, on the whole, favourable ³³³.

Much can be done for safety at night by the nature of the stone used for dressing employed on road surfacing, if uncoated. This should be light in colour; and when, for instance, $\frac{3}{8}$ -in. pea grit is used, motor headlights will show up a road for a considerable distance ahead.

Mirrors. Some years ago a half-hearted attempt to aid motorists was made by the erection of a mirror to show any traffic approaching from a side road. Many succumbed to the local sport of stone-throwing. More recently the suggestion has been revived, and an improved weather-resisting type is available ³⁷⁷.

Flares are worked by a petroleum distillate, and also by dissolved acetylene.

Traffic. The direct *control* of road traffic is in the hands of the police.

With the growth of motor traffic the police became increasingly directed to traffic-control duties away from their primary functions of preserving law and order, and the prevention and detection of crime. This led to the rapid extension of automatic traffic control signals (after development in America), which will be described on p. 283 *et seq.*

Control of traffic into lanes, and as a visible warning of possible dangerous encroachment, has successfully been effected by white lines along the surface of the road (see p. 23).

The control of the *speed of traffic* has undergone many changes from the days of the man with a red flag (abolished in 1878) to the abolition of the speed limit by the Road Traffic Act of 1930, and the

imposition of speed restriction in built-up areas in 1934. As motor vehicles increased in numbers, reliability, and speed, and the standard of driving and efficiency of control improved, the legal limit of 20 miles per hour had become practically a dead letter whilst remaining a potential weapon against the motorist. The position became so intolerable and ridiculous that Parliament by passing the Act abandoned speed limits—except in certain cases, in favour of increased penalties for ‘careless’ and ‘dangerous’ driving (see also ²⁷⁹). Since 1934 a maximum legal speed limit of 30 m.p.h. has been in operation on roads where there is public lighting, with a few exceptions which are indicated by a black disc with two diagonal white lines affixed to each lamp column.

The requirements of the *illumination* of vehicles at night are definitely laid down. The safety of a road depends very largely upon individual vehicles and drivers, but not so much as to make them the scapegoats of the road.

The *Horse-drawn* farm cart is holding its own in the country; and in town, short hauls are generally more economically made by horse transport than by mechanical vehicles.

Iron-tyred horse-drawn vehicles present a serious problem to the roadmaker all over the world, as they damage the surface of a road suitable for motor traffic far more than mechanically propelled vehicles. At the same time horse owners demand a non-slippery surface suitable for that class of transport.

The National Horse Association of Great Britain took an active part in supporting this demand, and secured much sympathetic and practical assistance of the Slippery Roads Committee of the County Surveyors’ Society.

The above-named Association contented itself, however, with an expression of its views on the anti-skid surfaces of certain roads, in some cases even naming proprietary forms of surfacing, and this did not carry the subject very far. No attempt was made to investigate the question of non-slip horse-shoes—an aspect of the question of major importance, having regard to the fact that horse traffic is now but a very small percentage of the total, and to the difficulty sometimes experienced of providing conditions at the same time suitable for both horses with steel shoes and motor vehicles with rubber tyres. Rubber shoes are in fact available which appear to have given satisfaction, but these have not been generally adopted.

The Society is now content to watch the roads in the interest of the horses, and to draw attention to unsatisfactory surfaces.

Modern Motor Vehicles, on the purely mechanical side, can contribute a great deal to safety by proper design and balance, and

adequate brakes accurately adjusted. The relation of driver to safety is ever being discussed, but no final result is reached.

Among the achievements of the Road Research Laboratory is the investigation of the skidding properties of various road surfaces by measuring the forces set up on a skidding wheel, fixed alongside a motor-cycle and side-car, or behind a lorry. A laboratory-scale machine has been described ⁵⁵⁵. This method has now an established position. As an example of the figures obtained by the Road Research Laboratory, the following have been taken from the British Report on Question 5 to the International Road Congress at The Hague, in 1938.

	Sideways Force Coeff. at		
	5 m.p.h.	15 m.p.h.	30 m.p.h.
<i>Concrete :</i>			
rough screeded finish	0.9	0.85	0.75
exceptionately smooth	0.6	0.4	—
<i>Tarmacadam :</i>			
hot, single coat, $\frac{3}{8}$ -in. chippings—			
new	0.95	0.95	0.9
after 6 years	0.85	0.55	0.3
<i>Asphalt :</i>			
rock asphalt—			
polished smooth	0.2	0.1-0.15	0.1 or less
$\frac{3}{8}$ -in. chippings—			
new	1.0	0.95	0.9
after 6 years	0.85	0.7	0.65
mastic, $\frac{1}{2}$ -in. precoated chippings	0.9	0.85	0.55
cold, no surface treatment—			
new	1.0	0.85	0.6
after 6 years	0.75	0.45	0.25
thin surfacing B—			
new	1.0	0.9	0.7
after 6 years	0.5	0.3	0.15
thin surfacing C—			
new	1.0	1.0	0.95
after 6 years	0.75	0.7	0.6
<i>Stone Setts</i>	0.55-0.3	0.45-0.25	0.3-0.2
<i>Wood Blocks :</i>			
new	0.8	0.7	0.55
old, some small stones	0.3	0.15	0.15
gravel dressed	0.65	0.45	0.4
<i>Rubber :</i>			
new	0.5	0.35	0.15-0.2
old	0.3	0.2	0.15

The Pedestrian can make a vitally important contribution to his own and others' safety, if he will exercise reasonable care and cross the road alertly and with intelligence. If only he would keep out of

the carriageway whilst waiting to cross, and would cross straight over instead of slanting (and so blocking the pedestrian behind him who is crossing straight over), much would be done to ease anxiety and danger.

Pedestrian crossings have afforded an excellent means of concentrating foot passengers at points where vehicular traffic expects them to be. Their highest value is lowered through the inattention of some drivers and pedestrians to their responsibilities (see *Highway Code*); nothing based on good will can survive without good will. At the same time, when he attempts to do his duty by observing the traffic signals he is not given the best help by them, as they were originally sighted for the control of vehicular traffic, and the pedestrian could not always see them, and could only take his cue from the traffic in the carriageway. Traffic lights and pedestrian crossings should be further developed for his safety.

The pedestrian is still unimpressed by the requirement that, in towns, he should walk along the left side of the footpath facing the oncoming traffic, so as not unthinkingly and unexpectedly to step off the kerb into the traffic stream.

In many parts of the country, lack of footpaths has been a contributory cause of accidents. In some cases paths have been provided on the field side of the hedge by arrangement with the owner, and this has been a valuable move in the right direction, but there are difficulties in the widespread application of this principle. When there is a footpath, the pedestrian should make use of it, but when he must walk in the road he should proceed on his right side so as to face any approaching traffic.

Lastly, the **Cyclist** who, together with the Pedestrian, too often ignores the *Highway Code*. He is the greater danger as his vehicle is unstable and more unpredictable than others. Separate cycle tracks along the side of the road increase the safety of all, even if they do not afford the continuous maximum convenience.

Finally, too great emphasis cannot be placed on the fact that road safety depends in a very great degree on the design of the road itself.

AMENITIES.

The planning of a road, whether in town or country, requires that engineering construction should be pleasing to the eye, and this aesthetic insistence is having an increasing importance attached to it.

The outcry against every new country road of importance ignores the possibility that with good planning the beauty of the landscape may be enhanced by making evident the gracious curve of a hill-side

or the aspiring rise of a glen. Trees, old or new, can be made valuable natural aids to roads in a landscape ; the choice between hedges and fences, and the architecture of garages and petrol stations are matters for most careful consideration. In America, the landscape engineer is a specific profession.

The planting of trees and bushes can make an important contribution to safety as well as beauty (see also ⁵³⁷).

In Towns. Roadside Tree Planting.

The provision of trees in and alongside roads and in streets often adds considerably to the amenities of a locality (see Figs. II.9 and



FIG. II.9.—Chalkwell Avenue in 1946.

II.10), but injudicious planting has done much to bring the practice into disrepute. There are positions in which trees are likely to be so obstructive to traffic or to light and air that the disadvantages outweigh the advantages. In all cases the choice of trees requires careful consideration in relation to soil, character of the road or street, and surrounding buildings, the aspect, and conditions of climate and atmosphere.

A mistake often made in the past has been the planting of large

forest trees, bearing large, tough leaves, such as the London Plane and Sycamore, in town streets. When the leaves fall they stick to the road in wet weather, and are liable to cause accidents ; moreover, they block the channels and gullies, causing flooding, and are difficult to remove.

Outside towns failure is usually the result of selecting trees unsuitable to the soil, but in town streets trees most often fail to thrive owing to lack of root space and of moisture and air to the roots, or to pollution of the atmosphere. Many young trees are lost by wilful damage, or damage by wind through being insufficiently supported. Leakage of coal gas is often fatal to trees, and where the soil has become saturated

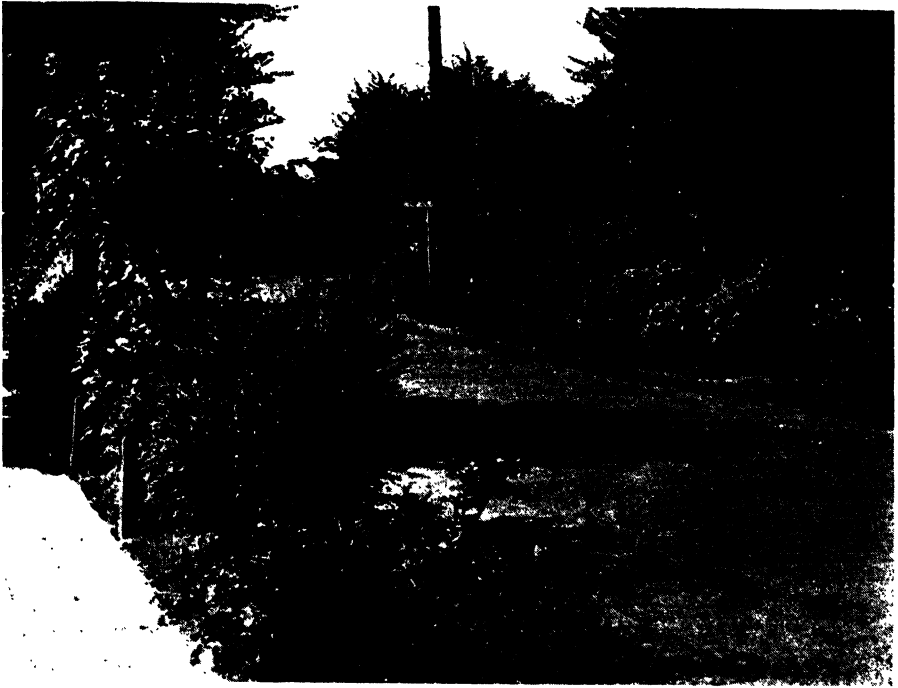


FIG. II.10.—Canvey Road in 1946.

with gas they should not be planted until a considerable time after the leakage has been stopped.

The appearance of very many street trees is spoiled by unskilful pruning : an example of bad pruning is seen in Fig. II.11. The course adopted in some places seems to be to let loose upon the trees, every winter, a gang of unskilled men armed with saws and hatchets to cut and slash them until they lose all their natural beauty. After such pruning they consist of a trunk surmounted by a few bare,

ragged and twisted stumps, which in summer and autumn become covered with a thick mat of twigs and leaves—neither ornamental nor useful. Where heavy foliage trees are planted too close to buildings or too near together, excessive pruning is often called for by persons who suffer from restricted light and air; the possibility of this happening after trees have developed should be borne in mind when they are being selected and their positions fixed.

The trees shown in Fig. II.11 are caricatures of trees, but the amenities of the road might be improved, by the removal of alternate trees and cutting away any awkwardly placed branches. After allowing them to 'break' again, and grow for a season, all growths should be removed at the end of the season, except one or, at the most, two vertical leaders, from each branch. After a few seasons, if all other growth is removed, there will, again, be some resemblance to a tree, and there should be little complaint of obstruction to light by the residents.



By the courtesy of The Roads Beautifying Association.

FIG. II.11.—Trees: Example of Bad Pruning.

For street planting trees should be well grown, with straight clean single trunks, well-developed roots, and good heads. The cultivation of trees suitable for this purpose is a long and costly operation and cheap trees are seldom satisfactory. During development, the young trees should be transplanted in alternate years and every effort made to encourage the formation of fibrous roots. Generally trees raised from seed are to be preferred. When large numbers of trees are required and the necessary facilities are available, it will sometimes pay a Council to order immature trees and grow them for two or three years, until they are ready for final planting. When planted upon footpaths trees should have a clean trunk of at least 7 ft. 6 in. and where public lighting is provided the trees should be of such a character and so planted as to cause as little obstruction to light as possible. Regard should also be had to the safety of vehicles, particularly where double-deck omnibuses are likely to run.

It is usual when inviting quotations for trees to specify (a) the height of tree above ground level ; (b) length of clean stem—ground level to underside of head—and (c) girth at 3 ft. or 4 ft. above ground level, but it is important that orders should be placed subject to inspection and selection at the nursery.

The dimensions will vary to some extent with the variety, but for street trees (a) should usually be 10 ft. to 12 ft. ; (b) 7 ft. to 8 ft. 6 in. and (c) 3 in. to 6 in. All trees should have been transplanted.

When practicable, trees should be planted not less than 5 ft. from the outer edge of kerb, and in any event at least 2 ft. Street trees are often planted too closely together. For the smaller trees the distance apart should be not less than 35 ft. to 40 ft. and larger trees should be given more room.

For planting, a hole at least 16 sq. ft. in area should be opened, but where practicable it is desirable that the hole should be 25 sq. ft., or more, in area. The depth should be not less than 2 ft.—preferably 2 ft. 6 in.—and the bottom broken up. Where the soil is unsuitable, part, at least, should be replaced with good friable loam ; the latter being carefully shaken and worked round the roots after they have been spread out in their natural position. The tree should be planted at the same depth at which it was planted in the nursery ; this is indicated by the soil mark upon the stem. The roots should be exposed as little as possible between the time of lifting and planting. If they become dry they should be soaked in water before planting. Unless the weather is very wet a good soaking of water should be given immediately after planting, not only to supply moisture to the roots, but to assist in consolidating the soil.

Staking should be thoroughly effective and should be continued until the trees are capable of standing alone without risk of damage during windy weather. One or, preferably, two substantial stakes should be driven firmly into the bottom of the hole before planting. Precautions should be taken to prevent rubbing by means of packing between tree-tie and stake. This may consist of felt, old rubber hose, linoleum, or other suitable material.

The amenities of residential roads may often be improved by the formation of planted borders on one or both sides (Fig. II.9) ; for example, many miles of such borders have been provided in residential districts of Southend-on-Sea (Westcliff, Thorpe Bay, etc.). The effect has been to increase the popularity of the areas and improve the value of property. The width of the borders varies according to the width of road ; in most cases the width of paved footpath is not less than 6 ft., and borders from 4 ft. to 8 ft. For some years landowners have found it to their interests to co-operate with the Borough Council to

provide sufficient width of road to permit of planted borders. The practice followed has been to plant rather closely small inexpensive flowering and ornamental shrubs and as they have developed to thin them out, planting those removed in other borders.

The following table contains a list of the more suitable trees for street planting, with information as to some of their principal characteristics (see also ^{417, 418}).

The planting of the central reservations of dual carriageways and of roadside waste and embankments and roundabouts on new roads calls for special care and consideration. Generally conditions permit a much wider choice of trees and shrubs than street planting in towns. It is important that priority should always be given to the primary object of reservations and roundabouts, viz. the safety and convenience of traffic. The effect upon visibility, lighting, etc., when the subjects have reached maturity should be visualized, and every effort made to reduce to a minimum the necessity for future pruning and trimming, which, otherwise, may become a matter of constant expense.

Great care should be taken to avoid a monotonous effect, by mixing varieties, irregular spacing, and, so far as practicable, general informality.

In long and unbroken stretches of a central reservation a clear view between the tracks is not of importance; in fact, one of the objects of planting should be the screening of drivers on one road from the glare of headlights on the other. At approaches to junctions, cross-roads, pedestrian crossings, etc., however, or where street lighting would not be prejudiced, low-growing shrubs or trees with clean trunks, only, should be planted.

Suitable shrubs include Hawthorn, *Berberis* (Barberry), particularly *Darwinii*, *stenophylla*, and *Aquifolium* (any soil), *Ulex* (gorse, furze in variety), *Cytisus* (broom) in variety, *Myrobella plum* (impene-trable hedge), *Escallonia* (warm positions only), *Euonymus japonicus*, Holly (dwarf varieties), Privet, *Tamarix* (Tamarisk) in variety (sandy loam), *Cotinus* (smoke bush), gorgeous colours in autumn on poor soils, *Cornus sanguinea* (Dogwood-coloured stems), *Rhododendron* (lime-free soils), and many others.

An effort should be made to select shrubs to provide some brightness and colour throughout the year.

Unless a central reservation is of exceptional width (at least 30 ft.) forest trees, such as beech, plane, chesnut, and maple, should be avoided. The extensive planting of laburnum, hawthorn, *Ailantus* (tree of heaven), Rowan (mountain ash), *Betula alba* (silver birch), *Salix* (willow) (in moist ground), *Populus* (poplars) *bolleana*, Wheatley Elm (heavy soils), *Tilea* (lime tree)—some varieties have yellow or

TREES FOR ROAD AND STREET PLANTING—continued

1	2	3	4	5	6	7	8	9	10
Name of Tree.	U. Upright. S. Spreading. C. Compact.	Growth: S. Slow. M. Med. R. Rapid.	T. Town. S. Suburban. C. Country Roads.	Suitable for			Leaves: L. Large. M. Medium. S. Small.	F. Flower- ing. O. Ornamental Foliage	Remarks.
				W. Wide Rds. N. Narrow. P. Parkways. A. Avenues. G. Grouping.	S. Almost any Soil. C. Chalk. Cl. Clay. G. Sand and Gravel. L. Light. H. Heavy. D. Dry. M. Moist. Lm. Lime. N.L. No Lime.	S. Smoky. W. Windy. SS. Seaside.			
THORN: (cont.)									
<i>C. Jacii</i>	S.C.	M.	T.S.C. Particularly suitable for S.	W.N.P.A.G.	Good for chalk		S.	F. & O.	Height 15 ft.—20 ft.
<i>C. punctata</i>	S.C.	M.	do.	do.	Good for clay		S.	F. & O.	Height 15 ft.—20 ft.
MAIDENHAIR TREE: <i>Ginkgo biloba</i>	C.	S.	S.C.	All except very narrow roads	Deep loam		S.	O.	Beautiful tree, but very slow growing.
DAVIDA: <i>Davidsonia or Fimbrinaria laeta</i>	S.	M.	C.	W.M.N.P.A.G.	S. Requires moisture		M.	O.	Somewhat similar to Lime. Fine tree. Rather tender. Height 20 ft.—40 ft.
BEECH: <i>Fagus sylvatica</i>	S. }								
<i>F. sylvatica cuprea</i> (Copper Beech)	S. }	S.	S.C.	P.A.G.	C.G. not Cl.			O.	Height 60 ft.—80 ft.
<i>F. sylvatica fastigiata</i>	U. }								
ASH: <i>Fraxinus americana</i> (American Ash)	S.	M.		P.A.C.	S.	S.	M.	O.	Height 40 ft.
<i>F. excelsior</i> (common native ash)	S.	S.		P.A.	S.	S.	M.	O.	Height 40 ft.—70 ft.
<i>F. crux</i> (Manna Ash)				W.P.A.				F.O.	Height 40 ft.—50 ft.
HONEY LOCUST: <i>Gleditsia triacanthos</i>	S.	M.	T.S.C.	W.P.A.G.	S.	S.		O.	Height 50 ft.
<i>G. elegansissima</i>	U.	M.	T.S.C.	W.M.N.P.A.G.	S.	S.			Attractive foliage. Height 50 ft.
SNOWDROP TREE: <i>Halesia caroline or tetraptera</i>	S.	M.	S.C.	Practically any roads	Sandy loam— not dry		M.	F.O.	Height 20 ft.—30 ft.
LABURNUM: <i>L. alpinum</i>	S.		S. principally	do.	S. not C.	S.W.SS.	S.	F.	Height 20 ft. Some
<i>L. vulgare</i>	S.	M.	do.	do.	do.	S.W.SS.	S.	F.	trees rather short- lived.
<i>L. sutchingeri</i>	S.	R.	do.	do.	do.	S.W.SS.	S.	F.	
TULIP TREE: <i>Liriodendron Tulipifera</i>	S.	M.		Requires plenty of room	S. Rather difficult to transplant			F.O.	Handsome large tree. Height 70 ft.—80 ft.
<i>L. pyramidalis</i>	U.	M.	C.						
PLANE: <i>Platanus acerifolia</i> (London Plane)	S.	M.	C.	Large leaves render it unsuitable for planting in roads or streets.	S.	S.W.	L.		Height 60 ft.
POPULAR: <i>Populus alba nigra</i> (White Poplar)	S.	R.	S.C.	W.P.A.	S. Requires moisture	S.	M.	O.	Tends to throw up suckers which may damage footpaths.
<i>P. Roletiana</i>									Useful ornamental tree taking little room.
<i>P. berolinensis</i>	U.	R.	T.S.C.	Practically any roads or position	do.	S.W.SS.	M.	O.	
<i>P. Eugeni</i>				do.	do.	S.	M.		Suggested for planting to indicate cross- roads.
<i>P. nigra pyramidalis</i> (Lombardy Poplar)	U.	R.	do.	do.	do.	S.	M.		
PLUM: <i>Prunus cerasifera Pissardii</i>	S.C.	M.	S.	W.M.N.	S. Requires lime. Not clay		S.	F.O.	Height 15 ft. Useful ornamental tree for suburban roads.
CHERRY: <i>Prunus Lannesiana erecta</i>	U.	M.	S.	W.M.N.	S. including Cl. but prefer light loam lime		S.	F.O.	Beautiful, towering tree requiring little room.
Many other trees included in the genus <i>Prunus</i> may be used with advantage as street trees, particularly in suburban districts.									
<i>Pyrus Malus:</i> <i>Crataegus Pyrus Malus:</i> <i>P. spectabilis</i>	S.C. }								
<i>P. spectabilis</i>	U. }	M.	S.	W.M.N.	S. Requires lime. Not stiff clay		S.	F.O.	Height 30 ft.
<i>P. spectabilis</i> Kaido	U. }								Height 35 ft.
<i>P. Tschonoskii</i>									Height 30 ft.
Many other trees of this group may be used with advantage as street trees, particularly in suburban districts.									
<i>Pyrus Sorbus:</i> <i>P. Aria majestica</i> (White Beam)	S.	M.	S.C.	W.M.	S. Particularly C.		M.	O.	Height 30 ft.
<i>P. Aucuparia</i> (Mountain Ash)	U.	M.	S.C.	W.M.N.	S.		S.	F.O.	Height 25 ft.—30 ft.
<i>P. Sorbus</i> (Service Tree)	U.	M.	S.C.	W.M.N.	S.		S.	F.O.	Height 20 ft.—30 ft.
OAK: <i>Quercus Cerris</i> (Turkey Oak)	S.	M.	C.	W.P.A.	S.	W.SS.	S.	O.	Height 30 ft.—70 ft.
<i>Q. coccinea</i> (American Scarlet Oak)	S.	S.	S.C.	W.P.A.	S. not stiff clay		L.	O.	Handsome tree.
<i>Q. coccinea splendens</i>	S.	S.	S.C.	W.P.A.	do.		L.	O.	Height 30 ft.—70 ft.
<i>Q. Ilex</i> (Holm Oak)	S.	S.	S.C.	W.P.A.	C. light soil	W.SS.	S.	O.	Height 50 ft.—70 ft.
<i>Q. pedunculata fastigiata</i>	U.	S.	T.S.C.	W.M.N.	do.		S.	O.	Height 40 ft.
ACACIA: <i>Robinia Pseudacacia Bessoniana</i>	S.	R.	T.S.C.	W.M.N.	S.	S.W.SS.	S.	F.O.	South coast. Height 50 ft.
<i>Robinia Pseudacacia Bessoniana</i> (Locust Tree)	S.	M.	T.S.C.	All	S.		M.	F.O.	The best of the Acacias. Other varieties brittle.
<i>Robinia Vignii</i>	S.	M.	T.S.C.	All	S.		M.	F.O.	Height 30 ft.—60 ft.
LIME: <i>Tilia vulgaris</i> (Common Lime)	S.	M.	C.	P.A.G.	S.	W.S.	S.	O.	Height 15 ft.
<i>T. euchlora</i>	S.	M.	T.S.C.	W.M.P.A.	S.	W.S.	S.	O.	Height 25 ft.
ELM: <i>Ulmus Montana fastigiata</i>	U.	S.	T.S.C.	W.M.N.	S.	W.S.	S.		Not recommended for streets. Leaves brown early. Drops sticky exudation.
<i>U. stricta</i> (Weedley) (Guernsey Elm)	U.	S.	T.S.C.	W.M.N.	S.	W.S.	S.		Handsome tree; the best lime for roads.
<i>U. cornubiensis</i>	C.	S.	T.S.C.	W.M.	S.	W.S.	S.		Height 40 ft.
									Best of the Elms for roads.

red twigs in winter, American Scarlet Oak, acacia, almonds, cherries, and other ornamental and flowering trees will produce decorative effects of great variety and extending over a long period.

All suitable existing trees should be preserved where this is practicable and satisfactory.

The advice of the Roads Beautifying Association, which is linked with the Royal Horticultural Society, is often helpful.

PART III

CONSTRUCTION

I

ROAD FOUNDATIONS

It has long been recognized that, whatever the type of road surfacing adopted, the provision of an adequate foundation is essential. The nature of foundation will vary with the character of the subsoil and formation, the character and weight of traffic, and the type of surfacing to be provided.

Generally, where new foundations are constructed, upon which is to be laid setts, wood-blocks, or asphalt, they are of concrete. Often, however, an old macadam road will form an excellent foundation for mastic or steam-rolled asphalt or for tarmacadam or concrete, if the latter can be superimposed without seriously disturbing the existing surface. Water-bound macadam is usually laid upon a stone-pitched, hardcore, or chalk foundation. In some cases it may be laid directly upon stabilized soil.

Where the sub-base is soft or of wet clay, a layer of 3 in. to 4 in. of ashes or clinker should be spread over the formation before pitching or hardcore is laid as, otherwise, the soil will spew up through the foundation material, under the weight of the roller. Chalk, of the right kind, is often very effective under such conditions, and forms a compact and continuous blanket. In some cases, for instance when road-work is being carried out during the winter, on very wet clay, the use of 'bavins' or faggots of brushwood may be necessary as a sub-foundation.

It is usually desirable to provide a layer of ashes or clinker under concrete.

Whether concrete foundations should be plain or reinforced, and, if the latter, what should be the weight and character of reinforcement, is a subject upon which there has been much difference of opinion. The fact is that conditions vary so greatly that it is dangerous to generalize. For instance, the late J. A. Brodie, City Engineer, Liverpool, found that conditions in that city rendered unnecessary

the provision of reinforcement, and that it served no useful purpose. Apparently climatic conditions in that part of the country are favourable, not only to the manufacture of cotton goods but also to concrete roads. Elsewhere, however, experience has been very different.

Soil stabilization is being increasingly adopted for strengthening the sub-base of concrete roads, and of concrete and other road foundations, and for roads carrying light traffic, such as agricultural accommodation roads. The process originated in America, and experience in this country is not yet very extensive, although it has been used on a fairly large scale in some districts, notably the County of Surrey. Details of the practice in that country were given in a paper read in February 1945 before a meeting of the Road Engineering Division of the Institution of Civil Engineers⁶⁰⁸ and the subject has been further discussed in other papers submitted to the Institution^{588, 589, 609, 610, 611, 614}. Reference is made to American practice in some of the professional and trade journals⁶¹³.

Work had already been begun at the Road Research Laboratory about ten years ago, and here and elsewhere—notably at King's College, Newcastle—a mass of knowledge had been acquired, but only with the advent of war did it become of high value.

The degree of stability of the subsoil results from the size and nature of the grains and the amount of moisture present, and, though of less importance in this country, from the effect of frost. In other words, drainage and compaction react on sand, gravel, clay, and other particles in a remarkable and complicated manner.

Soil stabilization is effected by compacting the soil to an adequate density, with or without the addition of other material, or by the admixture of cement with the soil, or by waterproofing it with bitumen or resin. Whatever the method, thorough compaction is essential. The process must be related to the character of the soil. Plant of various types is used for the purpose including (a) smooth wheel rollers; (b) sheepsfoot roller; (c) power rammers, and (d) mechanically propelled concrete-compacting machine, with single vibrating arm. (a) is not altogether satisfactory, as there is a tendency to the formation of waves, but these may largely be removed by the use of a light roller—say 3½ tons—for final rolling; (b) is useful on cohesive soil, and should be continued in operation until the feet fail to penetrate more than an inch; (c) has been found to be the most satisfactory on fine soils. A rammer of 50 to 60 lb. with stroke of 7–9 in., and working at the rate of 350 blows per minute, is effective for layers not exceeding 6 in. in thickness; (d) is said to give excellent results on a base of lean-mixed concrete.

It is advisable to cover the base with wet hessian immediately

after compaction, and the following day to spray the surface with bitumen emulsion. Where concrete is to be laid on the base, this should be done so soon as practicable, but tarmacadam should be delayed for about a week after compaction.

Where a binder is used two processes are available for mixing, namely, the mix-in-place method and the plant-mix method. In the former the binder, and any imported material, is spread over the soil to be stabilized. These are then thoroughly mixed with the soil, as they lay, by the use of a rotary tiller, and, as necessary, by such agricultural plant as spring-toothed harrows, heavy-duty disc harrows, and ploughs. The method is not very efficient, and prolonged and careful operation of the plant is essential to produce satisfactory results.

The second method can be controlled more effectively, and produces more consistent and reliable results. Ordinary concrete mixers may be used; and, for any but the smallest jobs, mixing in a central plant, and transportation of the mixed material by means of tipping lorries, or dump wagons, will usually be found to be of advantage. Double paddle mixers, as for asphalt, also are satisfactory. The control of the water-content is important, and should be within plus or minus of 3 per cent.

As a preliminary it is essential that a careful survey of the soil on the line of the proposed work should be made. The soil should be tested for optimum moisture content and for maximum density, by methods described in the Appendix to the above-mentioned paper ⁶⁰⁸. Where the soil has substantial natural stability, simple compaction may be sufficient to provide a suitable sub-base, but much depends upon the type and strength of the surfacing to be laid, and the duty for which the road is being designed. It may be desirable, even with a good-quality soil, to improve its strength by the addition of Portland cement, particularly where the surfacing material is tarmacadam or asphalt or where the stabilized soil is itself intended to carry light traffic, after being dressed with tar or bitumen and chippings. Too heavy a clay (giving large variations of volume according to its water-content) may be rendered less dense by an admixture of sand; too loose a sand may be given an admixture of clay. Binding materials usually employed are tar, bitumen, and cement—sulphite or lignin liquids from paper manufacture, or rosin preparations, have been used.

In Australia some success has been attained by the rather costly process of burning clay *in situ* ⁵⁵¹.

A further examination of the subject and a description of analytical methods is outside the range of present interests (but see ³⁶⁸).

II

PAVING AND SURFACING

These processes have been differentiated by the former being defined as consisting of separate blocks or units (such as wood paving, and setts), and the latter being formed of a continuous layer (such as asphalt, tarmacadam, concrete).

The laying of a block paving is, mechanically, a simple matter ; but the preparation of a surfacing is complicated, and may consist of mixing the stone and binder, spreading the mass, and rolling it. A third method consists of pouring the binder into the stone which has previously been spread in position—this is *grouting*.

This latter operation is described in connection with the various materials used ; but here the general nature of the process may be considered.

Grouting. The art of grouting consists in binding a broken stone road surfacing by means of a material of such temperature and viscosity that it penetrates to the desired depth and no farther. For this purpose the surface tension of the liquid has far less importance than the viscosity, so that the higher surface tension of tar is of no detriment—it is overcome by the lower viscosity which enable it still to penetrate well. Application must be carefully watched if the process is not to be wasteful in binding material.

The value of this mode of construction is well known, and it is particularly valuable for heavy gradients ; in fact, with gradients of, say, 1 in 8 to 1 in 5 it is often considered to be the only practicable method ¹⁶⁹ (see also pp. 131, 165).

The choice of methods for producing a traffic-worthy road is wide and varied, and the technique is full of subtleties and small details that control success or failure. But on one condition they are all dependent—they all require a substantial foundation.

The main determining factors according to which choice is made as to the most desirable type of surfacing are the relative cost of construction, length of life, non-skid qualities, absence of noise, cost of maintenance, and degree of interference with traffic during construction. In many cases, this interference with traffic and business, as for instance in busy shopping thoroughfares, is so serious that choice of surfacing is restricted to those forms of quick construction which ensure maximum durability with least amount of attention.

Where conditions are easier, less expensive forms of construction

may be adopted with satisfactory results ; until, for residential streets, with purely local traffic, cost becomes the main consideration.

Attempts have been made to devise a formula by which the highway engineer could determine the type and variety of foundation and surfacing that he should provide for varying volumes of traffic. All such attempts have failed, as indeed they were bound to do. The perfect paving, responding satisfactorily to all the varying conditions with which the highway engineer is placed, has not been discovered. The best, therefore, that the engineer can do in determining the surfacing to be used for a particular road, is to weigh the conditions—present and probable future—and then to select a surfacing which his experience tells him is likely to give the most satisfactory all-round service.

Such a choice will necessarily be in the nature of a compromise. Whilst desiring to keep down the cost, he must be prepared to pay a price that will command a good article. Available funds may not permit the adoption of the most expensive surfacing even if it has the greatest number of good points, and it may be necessary to sacrifice some length of life to avoid undue slipperiness, whilst risking some small tendency to skid under certain conditions in order to secure a reasonable standard of durability.

Moreover, no satisfactory formula has yet been produced which will enable the full effect of traffic of all kinds, under various conditions, to be satisfactorily assessed. For instance, what is the relation of different types of vehicles, of solid and pneumatic tyres, of differing loads of vehicles and differing intensities of traffic, to wear and tear of roads under all the various conditions which roads suffer ?

It is evident that there is a wide scope for the exercise of skill and judgment, and that there can be no hard and fast rule as to the surfacing which should be used upon different roads.

The range of choice undoubtedly increases as traffic conditions become less onerous. For instance, for roads with the heaviest traffic, say 20,000 tons a day and upwards, including a substantial proportion of heavy units, the range is limited to about six kinds of surfacing.

It is sometimes thought, and with justice, that the conditions insisted on by the Surveyor (and perhaps by the Police also) are unduly hard on the road maker, and prevent him from making the best of his job. The requirement that the road shall be reopened to traffic with the least possible delay necessitates the devising of methods and types of construction that shall take the heavy stresses quickly, instead of leaving sufficient time for a stronger and better method to 'settle-in.' It may be accepted that slower and more uniform work gives more lasting results and therefore better value to the public :

chemical and physical and mechanical changes must have time to take place completely, and the details of construction will be affected in less-harassed and breathless conditions. Only concrete defies this hustle.

III

ROAD CONSTRUCTION IN WINTER

The winter season used to be a busy time for road construction and maintenance in the days of water-bound macadam, but since the advent of bituminous and concrete surfacings most of the work has been confined to the late spring, summer, and early autumn.

Hot asphaltic mixtures, for premix, grouting, or surface dressing can be used satisfactorily only when the weather is dry and reasonably warm. The temperature limit has been lowered by the use of bituminous emulsions, whereby these operations can be carried out above 40° F. Tarmacadam can also be laid under similar conditions, though the quantity of tar present may be excessive on the arrival of hot weather.

Often it is desirable to carry out concrete roadwork during cold weather, and usually this can be done, in the south of England over a great part of the winter, if certain simple and inexpensive precautions are taken. This is possible, also, in other parts of the country, if more elaborate measures are adopted, but the question of increased cost will require consideration.

In mass concrete and slabs of substantial thickness (say 9 in. upwards), a more rapid increase of setting temperature may be obtained by increasing the proportion of cement by about 20 per cent. to 25 per cent., and this may be worth while—particularly with lean mixes—when temperatures are not likely to fall below, say, 38° F. In order to ensure freedom from damage to the finished concrete, the water-cement ratio should ordinarily not exceed about 0.7 ³²⁴.

Generally concreting should not continue when the air temperature is below 38° F. on a rising thermometer, and 40° F. on a falling thermometer, unless adequate precautions are taken. The most simple of these includes the protection from frost of all aggregate, and of the ground upon which the concrete is to be laid, by means of tarpaulins or other effective covering, for at least 36 hours before use. It may be desirable to place hurricane lamps, or other heaters, under the coverings, as it is most important that there should be no frost in the aggregate or formation when concreting.

Concrete laid when the temperature is below 45° F. should be protected in similar manner for at least 12 hours after laying.

The use of rapid-hardening cement (q.v.) is of particular advantage in cold weather.

The admixture of about 2 per cent. of calcium chloride with the cement accelerates the hardening of concrete, and the more rapid liberation of heat enables concreting to proceed at temperatures approaching the freezing point, but care must be taken to conserve the heat after the concrete is in position. Unless the men employed on the work are experienced in the use of calcium chloride, it is much safer to use one of the proprietary cements to which, already, it has been added. On large jobs it may be of advantage to provide plant for heating the mixing water and the aggregates when these have become frozen, but care must be exercised to prevent overheating of the latter.

The heating should be such that the concrete will not fall below 50° F. at the time laying is completed. This may involve the water being heated to about 75° F. when the air temperature is round about freezing, and about 140° F. when the air is 18° F. to 22° F. The heated water should first be mixed with the aggregate, before adding the cement. The concrete should be covered immediately after being laid to conserve the heat for at least 12 hours.

The introduction of bituminous emulsions has facilitated the execution of road work in winter. Materials pre-mixed or grouted with suitable emulsions can safely be laid in reasonably dry weather, when the temperature is above 40° F., and surface dressing can be done under similar conditions. Whilst tarmacadam may also be laid under such conditions, there is some risk that the quantity of tar used may be found to be excessive with the advent of hot weather.

Surface dressings applied hot are seldom quite satisfactory if the air temperature is less than 45° F.

PART IV

MATERIALS

I

ROAD-STONE

This country is fairly well and uniformly provided with road-stone of good quality, except in the east and south-east. The general excellence of available rock is undoubted, but the quality often varies even within the quarry.

Strictly, the interest of this book starts only after the stone has been quarried, crushed, and screened, and delivered for use on the road. Notice must, however, be taken of one link between the quarry and the road industry, and this is the astonishing inefficacy of the *nomenclature* which was for long imposed through its own inertia.

The quarry industry generally divides road rocks for broken stone into three divisions—granite, limestone, and gritstone ; and this after the British Standards Institution, backed by the Museum of Practical Geology (then in Jermyn Street), has settled the significance of geological terms with the agreement of the geologists and the trade. In spite of this, when granite is ordered a rock so different as basalt may be supplied ; and apparently some buyers do not mind (or even know), otherwise the practice would promptly stop.

It is not desirable to go to the extremes of which the professional petrologist is capable, but the correct class name, at least, is to be expected.

The following is a List of *Trade Names of Roadmaking Rocks* and their descriptions, drawn up for the use of engineers and the trade, with their agreement ¹⁴¹, together with the names of those rocks that the more generic name covers ¹⁴².

Granite. (Acidic.) A fairly coarse-grained, completely crystalline rock, consolidated at a great depth in the earth, composed of alkali-felspars, quartz, a ferromagnesian mineral, and less important accessories.

This term also covers : aplite, diorite, gneiss, pegmatite, syenite.
Gabbro. A rock, consolidated at a great depth in the earth,

thoroughly crystalline ; consisting essentially of soda-lime felspar and a pyroxene (usually diallage), and sometimes olivine.

This term also covers : norite.

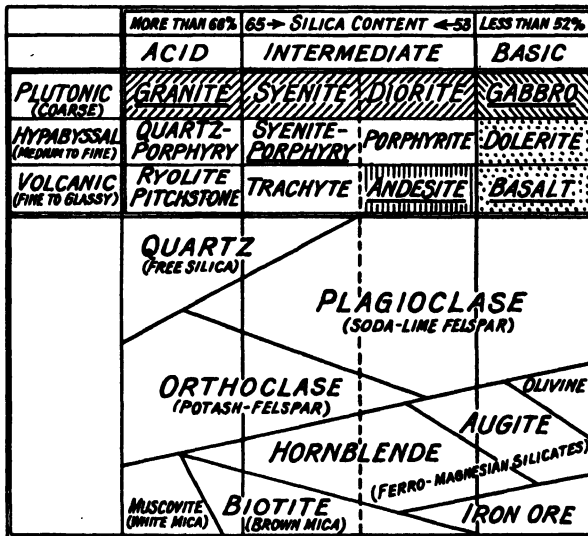
Porphyry. An igneous rock characterized by comparatively large crystals, generally of soda-potash felspar, in a finer ground-mass of felspar, quartz, etc.

This term also covers : felsite, granophyre, keratophyre, porphyrite, rhyolite, trachyte.

Andesite. A volcanic lava, intermediate in character between acid and base, consisting principally of soda-lime felspar and ferromagnesian minerals, usually without olivine.

This term also covers : dacite.

Basalt. (Basic.) (Including Basaltic Whinstone.) A dark-coloured igneous rock composed essentially of soda-lime felspar, augite, olivine, and iron minerals. Some basalts are lavas which have flowed out on the surface ; others occur as dykes and sills.



By the courtesy of Edgar Morton and 'The Quarry Managers' Journal.'

FIG. IV.1.—Diagrammatic Representation of the Composition of Igneous Rocks, suitable for Road-stone, and their Main Mineral Constituents.

This term also covers : diabase, dolerite, epidiorite, greenstone, lamprophyre, spilite, teschenite.

The geological-chemical relationship between these rocks are set out in sufficient detail for present purposes in Fig. IV.1 ²⁰⁵.

Hornfels. A fine-grained, compact, highly changed rock, the

original texture of which has been obliterated by the heat of an adjacent intrusion.

This term also covers : hornstone, mylonite, hornblende-schist.

Schist. A rock, of which the original character has been altered by the agency of heat, crushing, shearing, percolating water, or recrystallization, in which the minerals are arranged in sub-parallel bands or foliation.

This term also covers : mudstone, phyllite, shale, slate.

Quartzite. A rock composed almost entirely of closely fitting quartz grains, of which the cementing material is quartzose and crystalline.

Derived Rocks.

Grit. A coarse variety of sandstone.

This term also covers : arkose, breccia, conglomerate, greywacke, sandstone, tuff.

Limestone. A rock consisting essentially of carbonate of lime.

This term also covers : dolomite, ironstone, marble, and is, therefore, more elastic than the others.

Flint. This material consists of minutely crystalline silica, and sometimes shows remains of sponges and other organisms.

This term also covers : chert, pit and surface flint.

The **quality** of the rock for road purposes is determined by :

1. *Mineral Composition* and the associated properties of hardness, cleavage, nature of fracture, and toughness. Biotite mica, for instance, is soft with a perfect cleavage and is very disadvantageous ; felspar wears with a uniform saw edge on account of its crystalline shape and type of cleavage, and this gives an anti-skid surface ; quartz wears more rapidly than felspar on account of its ease of flaking.

2. *Grain size* is most important, as the finer the grain, the less rapid is the wear. The crystalline particles should preferably be all the same size.

3. *Rock Structure* determines the strength of a rock—the more the components interlock, the stronger it is.

4. *Decomposition* of the constituent minerals leads to general weakening.

5. *Recrystallization.*

“ In general, it is found that stone in which secondary mineralization has taken place is tougher than the same rock of the same kind, because the larger original minerals have been more or less replaced by firm and better-knit aggregate of new minerals amongst which secondary silica is usually predominant ” ¹⁴³. (See also ¹⁵³.)

Study is urged of the *Attrition Tests of British Road-Stones* ¹⁴² as

this brochure contains much valuable general information in support of the main matter, including the national resources of stone.

In this section of the road industry, as in others, science takes its position, and some admirable work has been done in co-ordinating microscopic appearance of rocks with their behaviour on the road ; to this further reference will be made in its proper place. It should, however, be emphasized here that this development has gone so far that information is available whereby every engineer can now select and specify that material that fulfils his requirements. Excellent microscopical work has been done by the Limmer and Trinidad Lake Asphalt Co. Ltd., and the Road Research Laboratory has a comprehensive collection of British mineral aggregates.

The **resistance** that road-stone has to exert is so well known that it only needs to be summarized :

Traffic.

Horse : impact of hooves and the digging action of the point of the hoof during the moment of contact with the road surface ; action of iron-tyred wheels, abrading and crushing the surface.

Motor : a shearing action by power wheels at the surface as a whole ; abrasion by chains and the like ; by the presence of grit under the power wheels.

Internal friction, under traffic.

Climate.

The action is not great on the stone itself, unless it is porous and exposed to low temperatures. The effect on fresh granites is extremely slow.

II

MINERAL AGGREGATE

So far, road-stone has been considered as a raw product of the earth ; it must now be examined as a constituent of a road surfacing in conjunction with other substances.

The wearing properties of igneous road-stone depend on ¹⁵⁴ :

- (a) the original mineralogical composition ;
- (b) the amount of subsequent decomposition ;
- (c) the texture, as exemplified in the Table on page 72 ;
- (d) structural weakness, such as cracks, cleavage planes, etc.

The shape of the fragments is of first importance in their contribution to their suitability for road purposes, in that long and thin

Texture.	Abrasion Test : % loss, av. wet and dry tests. (Lovegrove.)	Toughness. (Logan Page.)
Coarse-grained Granito	15	8
Medium „ „	12	10.5
Fine „ „	9	16
Micro-granito	7.5	19
Coarse Porphyry	6.3	22
Medium „	5.3	24
Fine „	3.6	31

fragments are liable to fracture. The most desirable are bulky pieces, commercially known as 'cubical.' The choice of this word is unfortunate, as it is a mathematical term to which the shape of a rock fragment seldom even approximates.

The mineral aggregate which is used in surfacing is supplied by the quarry or pit in various sizes determined by means of sieves and screens which should accord with B.S. 410 : 1943 and 481 : 1933. When suitably graded and mixed together with sand and filler, it is bound together by a bituminous or hydraulic cementing material. The range of sizes of the three main classes of mineral aggregate are :

Coarse Aggregate	retained 7-mesh.
Fine Aggregate	passing 7, retained 200.
Filler	mostly passing 200-mesh.

(The gauges for coarse aggregate and chippings have been standardized : B.S.S. 63 : 1939 ; 812 : 1943.) The grading for concrete (q.v.) approximates towards these proportions.

The ideal grading of the stone and sand is such that the final mixture should be almost as dense as possible, partly for the sake of the inherent strength of the mixture resulting from the wedging of the stone, and partly for economy in the most expensive component, the binding material. At the same time crusher-run stone should, theoretically, be most desirable, as being likely to re-form, when mixed, to condition of minimum voids, but actually it cannot be kept true to its grading. In any case the voids thus obtained are seldom below 25 per cent. The word 'almost,' used above, is of high significance, because in the case of the bituminous road the theory has developed away from the original idea of maximum density, as advocated for concrete, to a somewhat looser texture which shall be more yielding or shock-dissipating, whilst still remaining stable. A more non-skid surface is simultaneously developed. Latterly thin carpets have been developed having appreciable void content. Yet, as late as 1940,

a method has been devised for obtaining maximum density curves from eleven sizes of aggregate, from $2\frac{1}{2}$ in. to dust ⁵⁰².

The sand, in such a mixture, undoubtedly serves to fill the interstices of the coarser material, and, theoretically, the filler occupies those of the sand. Actually, however, the fine subdivision of the filler causes it to behave quite differently; and, even if a small proportion of the relatively coarse material it contains does form a part of the rest of the aggregate, the majority is taken up by the cementitious material to which it gives stability (see *Bituminous Roads*).

The required characteristics of a mineral aggregate are mechanical strength of the individual particles and the capability of interlocking with one another. A spherical shape gives the maximum strength and minimum interlock; and a flat and pointed form gives the contrary, together with resistance to compaction under the roller; an intermediate shape is required. The description of 'cubical' is objectionable on the grounds that it is an inaccurate description of the irregular lumps that are obtained: 'angular but not flaky' has been adopted in its place. The sand should be subangular. The fact that no mention is made of the shape of the filler particles is evidence that an important phase of the understanding of skidding and the stability of road mixtures has been overlooked. There is one exception to this statement: the flat shape of the particles of slate filler is said to make the mixture stodgy, though considerable quantities of the material are used.

The surface of the fragments, whether of stone or sand, should not be smooth, nor too porous nor cracked. It should preferably be rough so as to give a mechanical 'tooth-in-jaw' hold for the bitumen in addition to its adhesion through surface tension.

Voids.

The voids in a mineral aggregate are of vital importance to the stability of an asphalt, tar or concrete road; they determine the density of the mineral skeleton and, in a considerable degree, the quantity of binding material that is required. A theoretical investigation has been made⁹⁰, by the aid of lead balls and shot together with graphical means, of the sizes of successively smaller spheres that can fit into the interstices of the bigger ones, in order to produce a mass having the minimum of voids and maximum density. The possible arrangements of piling of the fundamental spheres are four—simple cubic, face-centred cubic, body-centred cubic, and hexagonal; and of these, the last is the most usual (Fig. IV.2). Taking the numbers of these various sizes of spheres, and converting them into

I.M.M. mesh sizes, the theoretical grading for the minimum voids of a spherical-grained sand is :

								%
Passing 200	.	.	.	.	.	.	.	17.1
100	.	.	.	.	.	.	.	0.7
80	.	.	.	.	.	.	.	0.2
70	.	.	.	.	.	.	.	0.7
60	.	.	.	.	.	.	.	0.8
40	.	.	.	.	.	.	.	1.6
20	.	.	.	.	.	.	.	4.7
10	.	.	.	.	.	.	.	74.2
								<hr/> 100.0

(Much of the early fundamental work was done with I.M.M. sieves, which are now obsolete. For a comparison between them and the B.S. series, see pp. 370, 374.)

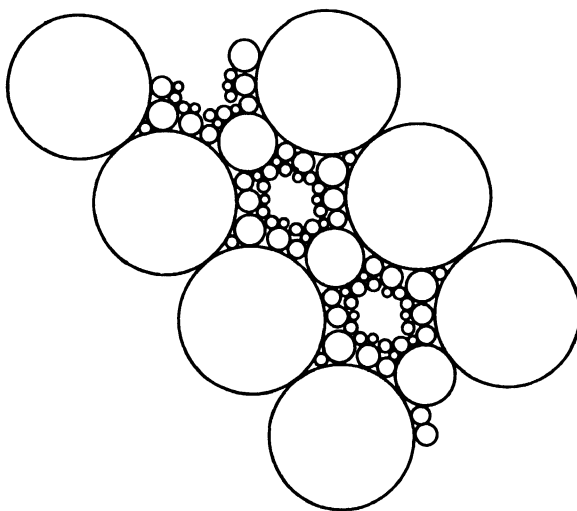


FIG. IV.2.

A sand mixture made up in these proportions did actually give a very hard mass on tamping, and, even though the grains were far from being truly spherical, showed 20.8 per cent. voids, as compared with 33 per cent. of 10-mesh material alone. When an asphalt mixture was made up on this basis, with the required minimum of 9.2 per cent. bitumen, it compressed to a well-knit block, but the grains were rather thinly coated and the surface was rough, as might be expected with a minimum addition of the binder. When this was raised to 12.2 per cent. a very tough well-knit mastic-like material resulted. This

sufficed to show that theory was right, but in practice deviations from this theoretical grading are required. This matter has been greatly developed in the direction of co-ordinating voids in sand and bitumen-sand mixtures with shearing stress, by means of a modified Hubbard-Field stability machine ⁴⁶².

• The sands usually employed contain 30–35 per cent. voids, reaching to 42 per cent. when very fine ; and the fillers, being very much finer still, may show 50–70 per cent. voids as customarily determined. (But see under *Tests*.) On an average, the sand grading usually preferred requires 10–12 per cent. of filler, of which either, more or less, *increases* the percentage of voids.

Regarding the desirability of minimum voids, it is logical to expect that the most stable roads shall be those in which the mineral aggregate is of such a character and is so graded and so closely packed that this interlocked and wedged framework will go far towards holding the mass together.

Experience supports this theory ; and a good example is seen in the many miles of old macadam roads throughout the country, which are composed of angular stones that have become so interlocked and consolidated by years of traffic that they have been successfully retained as a foundation for bituminous wearing surfacings. The binding material in these foundations is of the lowest possible quality—mainly dried mud ; but being left undisturbed and protected from attrition the road becomes almost as hard as concrete. A good idea for the reason for this will be obtained from the discussion of the chemical and colloidal changes which occur when water comes into contact with silicates (see *Cement*).

In a pre-mixed hot process this might be the ideal to which to attain, because each particle is coated before consolidation, and in the subsequent packing together during rolling the aggregate should take up its densest formation. If this did occur, however, there might be too little opportunity for the particles to rock against one another, under traffic, with that non-rigid property that is valued in bituminous construction. Also, there might be too little bituminous cement present to make the surface waterproof.

In the case of tarmacadam the matter is somewhat different. Mountsorrel granite, for instance, screened and dumped, has about 45 per cent. voids. The type of binder employed, together with the necessity for ease of handling, do not allow of a closely graded aggregate, as the finer material would make a pudding-like mix which would be difficult to spread and impossible to roll. Further, after consolidation, no appreciable evaporation of the volatile constituents would occur, and the resultant carpet would remain too soft for the carriage

of traffic. With the above considerations in view, the following grading has been developed, for a 3- to 4-in. carpet :

in.	%
to $\frac{1}{16}$	7
$\frac{1}{8}$	20
$\frac{3}{4}$	13
1	20
$1\frac{1}{2}$	20
$2\frac{1}{4}$	20
	<hr/>
	100

This grading has reduced the voids from about 45 per cent. to about 33 per cent., but further compaction occurs on the road without fracture of the stone ; an old road surface was examined and found to have 6 per cent. voids.

The whole question of voids received a shock when it was realized that the grading of sand, which was supposed to control the voids, did not always indicate the amount of bitumen required. Two sands of similar grading were found to differ in their bitumen requirements by as much as 1.5 per cent. (on the total mixture) : this deviation was ascribed to differences in shape and surface texture of the grains.

The shape of the grains has a very great influence ; when comparing the sands of similar grading, one with rounded grains and the other consisting of crushed flints, the minimum voids with a limestone filler was reached with 13 per cent. filler with the former sand, and with 30 per cent. in the case of the latter. For these reasons, together with the frequent difficulty and expense of achieving minimum voids, this ideal has been given up, and other aims have been substituted ; indeed, the whole problem has been considered from a different angle.

One fundamental quality that is required in a road surface, in order that it shall have a long life, is that it should be waterproof ; and for this, experience shows that a definite amount of binding material must be present. This requires the adjustment of the grading of the mineral aggregate to carry this, and also of the amount of filler—no longer for filling the voids in the sand, but for giving sufficient stability to the bituminous binder to withstand the weight of traffic expected.

Such modification of the older ideas has resulted from a long experience that permits of a less wide margin of safety, and successful road surfacings are being laid that would have horrified the older engineers.

An important reason for this change is the realization that in some degree length of life must be sacrificed for the sake of a safer surface.

When the problem consisted in fitting the bitumen or tar to the

voids in the mineral aggregate, the quantity required could be indicated, fairly accurately, by graphical methods^{94, 95}, but it is very doubtful whether these adequately replaced experimental determination. The correct proportion of asphaltic bitumen has been ascertained by the 'Pat Stain Number' (q.v.), which shows when the added bitumen is just beginning to be in excess.

Coarse Aggregate.

Granite, basalt, limestone, and broken flint and coarse gravel, are the typical rocks of this category that are valuable in road making, all being primarily tough and non-absorbent.

Granite is one of the most useful, and the most inconsistent in quality in the earth. It is used as road metal (with or without a bituminous binder) and also for kerbstones and setts (q.v.).

Basalt, including dolerite, diabase, some andesites, porphyry, diorite, and fine gabbro, when of the best quality, make the finest road-stones. (It will be noticed that this association of rocks is not identical with the classification given previously ; but serves for the purpose of criticism.)

Felsite, Rhyolite, are like the above, but are not so tough.

Limestone is a first-class road-stone when of a suitable type and proper quality. A fine-grained material is preferable, especially if dolomitized, as such formation or subsequent recrystallization of the calcium carbonate with magnesium carbonate leads to a strong micro-crystalline structure. Minute fossil remains are admissible, but not large ones, as these possess well-defined cleavage planes. The rock used is mainly of Devonian and Carboniferous age, with some Jurassic (which is harder)¹³⁹.

Limestone is remarkable for its affinity for tar and asphaltic bitumen (the curious unity of rock asphalt is evidence of this). (It is astonishing that flatly contrary statements have been made as to the chemical reaction between tar and pitch and limestone. Some deny there is any action, and some state this occurs²³⁹.) This affinity is also seen in the behaviour of limestone powder towards bitumen emulsions, which probably gives the clue to the mystery—a matter of surface tensions of the bitumen and of the rock ; but as so little is known about the surface tensions of solid substances, this clue cannot yet be followed to its conclusion. Limestone is thought to contribute to the slipperiness of some asphalt roads, and it is one of the remarkable gaps in highway knowledge that the matter is still undecided and vigorously discussed. It has, however, been found that the crystalline variety must be looked upon with grave suspicion.

The slipperiness of limestone, if it be a reality, may originate in two

different ways. Some limestones are affected by frost, and all but the hardest limestone will powder under traffic. If this occurs at the surface of a bituminous surfacing, the limestone may shed its coating of cementitious material and present a bare patch that is relatively soft and powdery, or produce a film on the surface of the road that may be slippery in wet weather.

Again, it has been found that limestone shows a preferential adsorption for the asphaltenes (the denser portion) in bitumen, which leaves the heavy oils free to make a lubricated surface.

Attention has been drawn to the possibility of the attack on limestone by atmospheric carbon dioxide dissolved in rain-water ¹²⁸. Usually, the older the geological formation from which the limestone comes and the higher its density, the more chemically resistant is it likely to be; and, as may be expected, the finer its subdivision, the more energetic will be the chemical attack.

A test can be carried out by immersing the sample in super-saturated CO₂-water (soda water, with the gas under 10 atmospheres pressure) in a closed vessel for 5 days; pouring off the liquid and replacing it by fresh for another 5 days' action; filtering the combined liquids into a platinum dish and igniting the residue at a low temperature. A similar quantity of CO₂-water is treated in the same way, as a blank.

Conversely, the limestone should be tested for the presence of calcium bicarbonate, which may exist in the upper layers of a quarry.

At first sight this may seem to be far-fetched as, in the solid state, calcium bicarbonate is stable only under a pressure of 15 atm., but it is the fact that small changes in the proportion of atmospheric carbon dioxide cause considerable alteration in the relative proportion of calcium carbonate and bicarbonate in solution.

Sandstone is fairly trustworthy when tough.

Flint remains unpopular.

Quartzite wears well, but has a low cementation capacity.

Schists and slates are rarely used, as being too soft, and breaking down into dust and mud.

Reference should be made to Road Research Special Report No. 3 (1946) on *Roadstone: Geological Aspects and Physical Tests*; a valuable short summary ⁶⁰³.

Gravel. The continuous search for a road surfacing that shall be ever cheaper and, at the same time, be of sustained or even increased efficiency, has led to anxious attempts to use local aggregate. Amongst these is gravel. It has long been an intractable material, and used mainly in the lower course, where it is protected from horizontal stresses. Its smooth surface has been obviated in a considerable degree by crushing, and by surface treatment with Portland cement

or lime to overcome its hydrophilic nature, thereby increasing its adhesion and stability. (See p. 138.)

Slag. Blast furnace slag has taken an important place in the manufacture of asphaltic and tarred macadam, and is the most important member of this class of materials. It varies much more widely in its quality and suitability for road making than natural stone, and it has to be carefully watched.

It is obtained in the form of 'ladles,' weighing from 5 to 15 tons. The awkwardness of handling such great masses is leading to the use of moulds, though rapid cooling leads to a denser and more brittle and less tough material, less suited for road purposes, but, at the same time, it is given a tendency to greater stability.

Its composition varies between the following limits :

Silica	27.00-37.00
Alumina	10.00-21.32
Lime	31.00-46.00
Magnesia	2.00-10.00
Iron Oxide	0.00-7.00
Manganese Oxide	0.00-4.64
Sulphur	0.00-1.80

These substances are combined to form three main substances, all crystallizing in the tetragonal system : sarcolite, $3\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$; ackermanite, $8\text{CaO} \cdot 4\text{MgO} \cdot 9\text{SiO}_2$; and velardenite, $2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 3\text{SiO}_2$. Together with these there is calcium orthosilicate, Ca_2SiO_4 , which exists in three forms. This is a most important substance, as the change from the β to the γ form is accompanied by a large change in volume ; and this is the major cause of the disintegration of slag, even in absence of water and after long delay. Such a change does not always occur, and well-matured slag of recognized quality is above suspicion.

Sulphur is introduced mainly through the ash in the metallurgical coke, and usually exists as calcium sulphide. This easily changes by the action of water into calcium hydrosulphide, $\text{Ca}(\text{SH})_2$ and calcium hydroxide, $\text{Ca}(\text{OH})_2$; and further changes ultimately lead to the formation of calcium carbonate and sulphuretted hydrogen, H_2S .

Any sulphur present as sulphate is innocuous.

In its satisfactory qualities, slag is dense, rough of surface, of a toughness comparable to that of granite, and showing a crystal grain size of 0.5 to 1.5 mm. ; when unsuitable it is porous and glassy, and even frothy.

The porosity, which is desirable to a certain degree (see *Absorption of Vibration*), is an uncontrollable matter, resulting from occurrences within the furnace.

The fundamental work on the stability of slag has been done in Germany, from which definite conclusions have been drawn ; and the whole matter of Tar-Slag Roads has been discussed ⁵⁵.

The permanence of slag depends on its chemical composition (and, to a less extent, on its mode of cooling), as spontaneous physical decomposition occurs when the slag contains too much lime or too much iron. Lime breakdown occurs when the lime exceeds 45 per cent. (it is preferably limited to 40 per cent.), and this leads to a safe limit for the lime-silica ratio of 1.28 to 1.30. The iron breakdown may result when the iron content is over 2 per cent. The lime trouble occurs from crystallization changes, which can be avoided by correct chemical composition, and by the rapid rather than slow cooling of the molten slag.

The nature and testing of Blast Furnace Slag is controlled by the War Emergency B.S. 1047 : 1942. (See also under *Concrete*, p. 195 ; and ⁶⁰⁷.)

Generally, slags, containing calcium orthosilicate, or emitting a perceptible odour when struck with a hammer, are to be rejected.

Clinker.⁸¹ The value of destructor clinker results from its rough-edged and angular character (when not over-milled), and the employment of an otherwise useless municipal waste material. Clinker from destructors dealing with town waste of varying character showed a substantially constant quality providing it is thoroughly burnt in high-temperature furnaces. Of other clinkers and boiler waste, considered experimentally, that from gas works most nearly approximates in value to destructor material.

As in similar cases, when grinding, the fan-drawn and fine-mesh powder can be used as filler. The fullest account so far available is that by A. F. Badman ⁵¹³.

Chippings consist of good-quality road-stone crushed to $\frac{1}{2}$ – $\frac{3}{8}$ in. Their principal use is in surface dressing, for reducing slipperiness of asphalt, tarmacadam, and wood paving ; also for closing too open a surface, and as ' armour ' to wood blocks. Coloured chippings from naturally coloured rocks ⁵⁰³ are used in residential neighbourhoods ; and light-coloured material has been tried for the increase of safety in night driving.

Fine Aggregate.

Sand is the detritus of any rock that is sufficiently broken down in size.

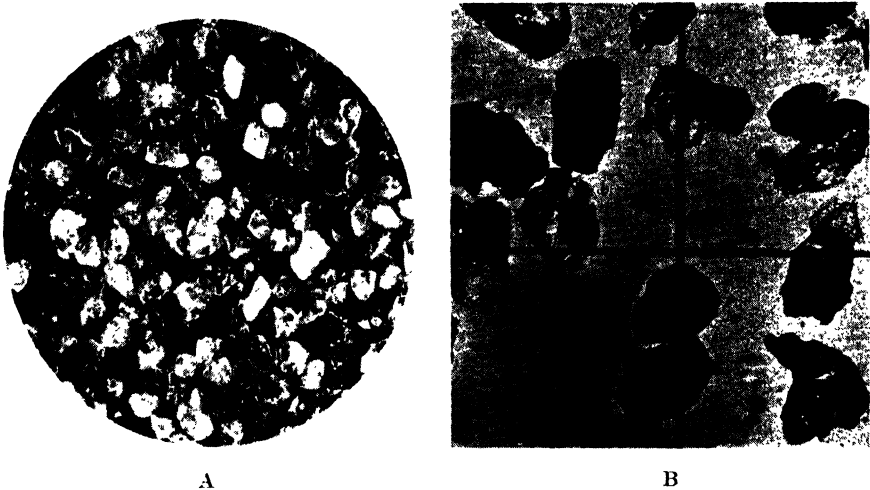
Its *chemical composition* is immaterial for road purposes so long as it remains unchanged. It may consist of felspar, quartz, and other granitic constituents ; or contain compounds of iron, like the green-

sands ; or again may be of substantially pure silica, as in the cases of quarry and sea sands and, in the amorphous form, flint.

The *shape* of the grains for bituminous construction should be sub-angular, as a compromise between sufficient interlocking, the best degree of packing, and the required 'give' of the final mixture. Pointed, flat, or flaky fragments must be severely limited in number on account of their structural weakness ; and shell is additionally objectionable owing to its capacity of absorbing bitumen and removing it from its position as a binding material.

For the making of concrete, rounded grains are admissible.

The quantity of mica present can be estimated by the eye in the



By the courtesy of the Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. IV.3.—A. Example of a Good Sand. $\times 23$.
B. Crushed Igneous Rock. $\times 80$

heavier portion of a sand separated by cadmium borotungstate diluted to a sp. gr. of 2.70. Fig. IV.3, A, shows the characters of a good sand.

The *surface* should preferably be rough rather than glassy, and not so pearly as to remove much of the bitumen binder from the mixture.

A *clean* sand is essential. This word has two meanings—freedom from admixtures, such as clay and humus, and freedom from incrustations. The former unbalances the mixture in an irregular degree, and may cause balling ; and an incrustated sand may lead to balling by interlocking (in a very bad sand), and the coating may break away in the mixture and leave the sand grains unattached to the binding material.

The *grading* of the sand is outlined in the British Standard Specifications.

Much work has been done on the connection between grading, character of surface of grains and voids ²²³, but this interesting matter cannot be discussed here.

The sand must be practically *non-absorbent*, otherwise serious failures may result. Any bitumen taken into the aggregate ceases to act as a cementing agent, and consequently the proportion of effective bitumen may be reduced to such a degree that the mixture disintegrates under traffic. For example : the specification for a sand carpet provided for 11 per cent. of bitumen which had been found quite satisfactory with apparently similar constituents. The road failed within a few weeks of completion and an examination of the carpet disclosed the fact that the sand, which had been obtained from a different source, contained shell debris which had absorbed about 5 per cent. of bitumen, leaving only 6 per cent. to function as a cementing material. (See also ¹²⁶.)

Filler.

At first the function of filler in asphalt and tarmacadam was misconceived. It was thought to fill the finest of the interstices of the mineral aggregate. Later it was realized that it stiffened the bituminous binder by increasing its viscosity ; and then a vast amount of work was done on the chemical nature of the filler, means of measuring the sizes of its particles, and its physical behaviour in contact with bitumen and tar.

Any finely divided material *may* make a good filler, but a very careful examination is necessary, before its adoption, into the following characteristics :

1. It must be *chemically inert*, so as to be incapable of reacting with the bituminous binder or with water. It is true that all well-made bituminous surfacings are impervious to water, but the surface tension relationships of binder-rock-water are such that water tends to enter between the rock and the binder if it has the opportunity through bad adhesion ; therefore, as a precaution it is wise not to employ a filler that reacts with water. If this were strictly followed, Portland cement would be excluded (as it is in Germany for this very reason) ; but in this country it is a popular material. It may be considered to be unduly risky to employ a filler that is relatively easily soluble in water (such as lime), as it might cause trouble in circumstances which might otherwise have been only doubtful.

2. It must be *physically active*, that is, it must show vigorous surface adhesion to the binding material ; and the degree of this ' affinity ' can be ascertained by physical-chemical methods ^{29, 123, 124, 125}, and by extrusion machines, big-scale penetrometers, and the like.

3. The *specific gravity* should be low, because the presence of the filler in the mixture is a volume matter, and the lower the specific gravity for a given weight, the greater is the volume. But if it be too low, difficulties in operation may result.

4. The *size and grading* of the particles is a very important matter. A filler is usually judged by the proportion passing the 200-mesh sieve, but this is seriously inadequate. The behaviour of a finely divided solid changes with such enormous rapidity with the diminishing size of the grains and associated increase in the total area of surface, that an accurate determination of the proportion of the ultra-fine particles must be made. This can be done by means of the flourometer (q.v.) or other form of fluid separation of the particles, and experience shows that a satisfactory filler does not contain less than about 60 per cent. of flour. This test is of great value, but is not applied as universally as it should be; and even this should be supplemented, as required, by further elutriation as far as the equivalence to a 500- and 800-mesh sieve. An appreciable proportion of 500-mesh material and little 800-mesh is recommended. Valuable and detailed work has been done showing the great variation in the proportions of the sizes of the particles, all of which pass the 200-mesh sieve.

Typical examples of the sieve grading of fillers which were in common use are the following ³¹⁵, but this was before the B.S. 594 : 1935 and 1945, which requires all fillers to have 85 per cent. material passing a 200-mesh sieve.

I.M.M.		Portland Cement.	Lime- stone.	Chalk.	Slate Dust.	Clinker.
		%	%	%		%
Passing 200 mesh	. . .	85.3	72.4	76.5	82.2	89.5
100 "	. . .	14.3	25.0	12.3	16.7	6.6
70 "	. . .	0.4	2.2	1.6	0.3	3.1
50 "	. . .	—	0.3	1.8	0.2	0.8
30 "	. . .	—	0.1	3.2	0.1	—
20 "	. . .	—	—	2.2	0.1	—
10 "	. . .	—	—	2.4	0.4	—
		100.0	100.0	100.0	100.0	100.0
Flour		71.4	68.0	75.0	70.2	77.3

The most valuable of recent investigations of the suitability of a powder for road purposes is the recognition that its bulk density, after settling in benzene, is a measure of its behaviour in a mixture with

bitumen or tar. It is the combined result of wetting power, grading, and proportion of the sizes of the particles ⁵⁰⁰, and it shows that equal volume of different fillers have the same quantitative effect on the viscosity of the binder, irrespective of the nature of the filler.

5. The *shape* of the particles is in all probability very important in connection with its effect on stability, but very little investigation seems to have been done upon this problem, except in the case of slate, where the flat shape of the flakes is considered to cause a stodgy mixture.

The *materials* that are employed as fillers are the following :

Brick Dust. This gives excellent mechanical tests, owing to its large area, but may be highly absorbent.

Clay, from layers in limestone, finely ground, has been successfully used, but is, on the whole, undesirable.

Coal Dust. A research was carried out in this country on the effect of finely powdered coal dust on coal tar ¹¹¹. Practical experience of this during 1930–2, in France ³¹⁴, has shown that immediately after chipping and rolling cars could pass at high speed without appreciable displacement of the chippings. The matter is complicated, as the powdered coal does not act as a simple filler only, but may alter the nature of the tar in the direction of asphaltic bitumen. (See also p. 114.) It is no longer used.

The addition of 23 per cent. to a proprietary bituminous cut-back produced a comparatively slight increase in viscosity, but raised the temperature of application by 15° C. In Paris such a material carried heavy traffic for 4 years ³⁵⁸.

Cyclone Dust (from aggregate dryer). This is used occasionally, when suitable in quality.

Diatomite is extremely absorptive, and thereby removes much of the binding material from active use in the mixture ; it is therefore of doubtful value.

Granite Dust has a considerable popularity, but is variable in composition, and does not differ greatly from silica dust.

Limestone. This is a popular filler, when it comes from an amorphous and not a crystalline rock. There is a definite excellence of adsorption between it and asphaltic bitumen and tar, but it is suspected of contributing to slipperiness.

Portland Cement is too well known to need comment. Free lime is an occasional impurity, which is considered to be undesirable.

Silica. Silica has low adhesive and cementation properties, and might cause silicosis amongst the workmen. There are many qualities, and that used must be high in percentage of fine material.

Slate. This is used in a considerable degree, but has been blamed

for causing stodgy or greasy mixtures, probably from the flatness of its particles.

Magnesia, Gypsum, Anhydrite, Iron Oxide, Strontium Sulphate, Barytes have all been used. The last is absolutely inert, but it is very heavy and therefore costly.

The *Symposium on Aggregates*, organized by the Road and Binding Materials Group of the Society of Chemical Industry (1937), contains much valuable information, including work on which certain Standard Specifications have been based ⁵¹⁶.

At first, the question of the properties of *bitumen-filler mixtures* was inadequately studied as a comprehensive subject, considering their importance in the stability of bituminous roads ¹⁷. A valuable investigation has shown that, when a number of fillers were mixed in increasing proportions with Mexphalt E grade, and the resulting *rise of melting point* was plotted against the ratio (volume of filler)/(volume of bitumen), up to a ratio value of 0.5 the increase of melting point was approximately proportional to the added filler, but that there was considerable variation at higher ratios. There is also a reduction in susceptibility to temperature.

As might be expected, the fineness of subdivision of the filler had a direct influence on their *stabilizing powers*; also, that it was found possible to give this numerical expression by means of the equation

$$R = K\sqrt{D}$$

where R represents the rise of temperature of the m.p. of the bitumen,

D represents the average diameter of the filler particles,

K represents the stabilizing power of the filler.

The results are given in the Tables :

RISE IN MELTING-POINT CAUSED BY TYPICAL FILLERS

Type of Filler.	Average Particle Size.	Rise in m.p. (° C.) of the Mixture when the filler/bitumen =	
		0.5	0.75
	μ		
Granite Dust, No. 2	9.7	22.0	81.0
Slate Dust	19.5	21.5	86.0
Limestone Dust	21.8	12.4	23.5
Rapid-hardening Cement	22.0	22.4	40.0
Whiting	23.2	15.0	32.4
Continental Cement	42.0	14.5	25.8
Granite Dust No. 1	44.0	8.4	33.5
Ragstone Dust	51.5	15.0	37.3

RELATIVE STABILIZING POWERS OF TYPICAL FILLERS

Volume of Filler/Volume of Bitumen

	0.5 R/V D		0.75 R/V D
Ragstone Dust	107.5	Slate Dust	380
Rapid-hardening Cement	105.0	Ragstone Dust	268
Slate Dust	95.0	Granite Dust No. 2	252
Continental Cement	93.0	" " No. 1	223
Whiting	72.2	Rapid-hardening Cement	188
Granite Dust No. 2	68.5	Continental Cement	167
Limestone Dust	58.0	Whiting	156
Granite Dust No. 1	55.8	Limestone Dust	110

In practice, the filler-bitumen ratio is usually 0.74-1, so that the results will most probably be close to those in the Table.

Another research ²⁰³ has produced such valuable results, that the authors' summary is reproduced :

" A. The melting-point, hardness and tensile strength are raised and the ductility decreased by the following factors, two or more of which may operate simultaneously :

1. Increase in the proportion of filler.
2. Increase in the hardness of the bitumen.
3. Increase in the fineness of the filler.
4. Fibrous or lamellar as distinct from cubical structure of the filler.
5. Increase in the bitumen adsorption power of the filler.

There appears to be no direct relationship between the chemical composition of the filler and the strength, etc., of the A.C. [asphaltic cement] made therewith. This is similar to what occurs in the case of fuller's-earth and other decolorizing powders, whose adsorptive properties appear to depend more upon their physical structure than upon their chemical composition.

B. The properties of the A.C.'s are so much dependent upon the properties and nature of the filler that examination of the bitumen alone for hardness, etc., is not sufficiently informative.

C. Owing to the absence of any simple relationship between the penetration, ductility, tensile strength and melting-point of the A.C.'s each of these properties must be determined if proper conclusions are to be arrived at concerning the suitability of the A.C. for a given purpose.

D. The ductilities of bitumens decrease to so marked a degree on the addition of fillers that the ductility of the original bitumen cannot be considered a guide to the ductility of the A.C. Broadly

speaking, however, the higher the ductility of the bitumen (for a given penetration) the higher will be the ductility of the A.C. The very high ductility of certain grades of modern residual bitumens of high and moderate penetrations (ductilities of over 115 cm. at 77° F.) is considered by some asphalt technologists as unnecessary, but it would appear that these high figures result in a definite improvement in the very much lower ductilities of the A.C.'s rich in filler and may, therefore, be desirable. In this connection the penetration of the bitumen must be taken into account, as the falling off in ductility on the addition of filler is much more marked in the case of the lower penetration bitumens.

Perhaps the most important conclusion to be derived from this research is that unless the ratio of the proportion of filler to bitumen in asphalts is maintained within fairly narrow limits, it is impossible to manufacture asphalts of consistent properties however constant the proportion and properties of the bitumen itself. Thus, failure of asphalts, such as marking under heavy standing loads, traffic, etc., often ascribed to defects in the bitumen, are really due to the use of an incorrect filler-bitumen ratio."

These conclusions are based on a study of mixtures of 40/50, 60/70, and 120/210 penetration bitumens, with the following fillers: semi-colloidal silica, Portland cement (normal grade, and also portion from air separator), ground chalk, ground limestone (original sample, 200-mesh material screened from this, and also 120/200-mesh material), micro-asbestos, slate dust, and mineral filler from Trinidad Lake Asphalt. The tests applied were: melting point, penetration, ductility, and tensile strength. (See also ¹⁸¹.)

The whole matter was gone into with great thoroughness in a valuable series of Papers to the World Petroleum Congress, London, in 1933 ⁴⁵¹. Later work, in general substantiation of Evans, showed that the power of a filler to raise the melting point and hardness of bitumen was not directly proportional to its absorption or decolorizing properties ³⁹⁴.

The variation in *ductility* and *penetration* of Mexphalte 45 with two different types of mineral matter have been determined:

Mexphalte 45.	Mineral Matter.	Ductility.	Penetration.
%			
100	—	+ 100	40
70	Portland Cement 30%	22	33
70	Aylesford Sand 30%	10.5	34

The gradings of the mineral matters were :

				Portland Cement.	Aylesford Sand.
Passing 200-mesh Sieve (I.M.M.)	.	.	.	77.2	0.5
100 " "	.	.	.	22.0	6.7
70 " "	.	.	.	0.4	38.4
50 " "	.	.	.	0.2	38.8
30 " "	.	.	.	0.2	14.4
20 " "	.	.	.	—	0.8
10 " "	.	.	.	—	0.4
				100.0	100.0

Much later the importance of bulk density has been realized, where the same bulk volumes of various fillers, when mixed with bitumen, gave rise to the same viscosities, whatever the nature of the filler.

Also, that there was removal of resins by adsorption and that this reduced the viscosity of the mixture ⁵⁰⁰.

Work of another kind had previously been done ¹⁹⁵ by dissolving the bitumen or tar, shaking it with the road-stone reduced to a powder, and determining the amount of bituminous matter remaining in solution. The descending order of excellence was found to be : Trinidad bitumen, Mexican, Californian, Tar ; and slate, basalt, porphyry, limestone, quartz powders.

An interesting examination of the subject has been made from the opposite point of view than that of stability—which filler tended to cause the break up of an asphalt surface by facilitating the formation of a bitumen-in-water emulsion whereby the bitumen would be removed from its mixture in the surfacing ¹²⁵. It was found that bitumen-in-water emulsions were favoured by silica, iron oxide, and gypsum ; whilst limestone, magnesium carbonate, slaked lime, magnesium hydroxide, and Portland cement all favoured water-in-bitumen emulsions, i.e. all tended to leave the bitumen in place in the road. Slag entered into both categories, according to the source of the samples. This explains the long-standing empirical liking for Portland cement and limestone as fillers. Further, it was found that the addition of some limestone to a siliceous powder overcame the latter's undesirable properties as a filler.

(See also ref. ¹⁴⁹ ; and p. 126.)

The properties of *tar-filler* mixtures have received considerable attention in the last few years.

A filler is added to tar for use on those roads only which require a semi-solid binder of low temperature susceptibility and plastic quali-

ties. Normal road tar is claimed to be satisfactory for surface dressing without such additions. It has been found ²¹⁶ that when an inert filler (defined as passing a 100-mesh sieve) is added to tar of less than 10 secs. viscosity and in quantities of less than 15 per cent., the viscosity increases according to

$$V_f = V^x$$

where V_f represents the viscosity of the tar-filler mixture,

V " " " " " tar at the same temperature,

x varies with the percentage of the filler according to the equation

$$x = 0.0085f + 1$$

where f represents the percentage of filler added.

Freshly made mixtures with limestone filler conform to the above equation; but if testing be delayed, a spontaneous rise in viscosity occurs till a maximum is reached after about 24 hours, when $V_1 = V^{x^2}$, where V_1 is the final viscosity.

At first sight this change might be thought to be associated with the ageing of the tar that has been referred to elsewhere, but it is more likely to be an adsorption effect, as it is observed with limestone fillers and not with granite dust.

As in the case of asphaltic bitumen, there is a diminution of susceptibility to temperature.

III

BITUMINOUS MATERIALS

Nomenclature and Definitions.

The confusion in the meaning of the words 'asphalt' and 'bitumen' had long been so great that the 5th International Road Congress (of Milan), in 1926, passed a resolution, asking the Permanent International Association of Road Congresses to take steps to define these terms. As a result, there was appointed a Committee to sit in Paris (the head-quarters of the Association), representing nine countries and languages, with terms of reference wide enough to deal with words associated with road making and with tests of many of the materials employed.

An outcome of the activities of this Committee was the appearance in 1931 of a *Technical Dictionary of Road Terms in Six Languages* ³⁵ (English, Danish, French, German, Italian, and Spanish), in tentative form to serve as a basis for further consideration. This was printed and issued to the public, and naturally caused much disappointment

to those who attempted to use it, and dismay to those who knew of its incomplete nature. At long last, the British section was ready for publication—just before the beginning of the Second World War, when it was rushed to this country just in time for its safety.

Agreement could be attained only after long discussion, and certain important concessions were made for the sake of world-wide agreement; but even so, America, who took no part in the discussions, found it impossible to agree in every case. When this occurred, both majority and minority definitions were accepted, so that a perfectly clear understanding, if not perfect agreement, was reached.

In the meantime, most of the important decisions have been included almost without change in the *B.S. Glossary of Highway Engineering*, 892:1940. Unfortunately—as introducing the possibility of confusion—the petroleum industry has more than one glossary for its own purposes, the most important being that of the Institute of Petroleum.

(For the derivations of many road terms, see ⁵¹¹, ⁵¹².)

Bitumen.—"Mixtures of hydrocarbons of natural or pyrogenous origin or combinations of both (frequently accompanied by their non-metallic derivatives), which can be gaseous, liquid, semi-solid or solid, and which are completely soluble in carbon disulphide."

This is the American definition accepted by the Committee. It will be seen that the main effect is to include under one heading the CS₂-soluble matter in tar with the similarly soluble matter in petroleum residues and naturally occurring oil products; as well as such widely separated substances as natural gas and paraffin wax. Dislike was at first expressed at so broad a definition being adopted, but it was found that the breaking of the barrier between tar and petroleum products was welcomed by the industry. Thus, 'bituminous materials' are those that contain bitumen, as above defined; the old term 'bitumen' as applied to road materials, now becoming 'asphaltic bitumen.'

It will be seen below that 'Asphalt' in association with 'hard' and 'soft' has become too deep-rooted to be dislodged.

ASPHALTIC BITUMEN AND ASPHALT

The material that is used in this country for road purposes consists of heaviest portions of asphaltic-base petroleum produced in a refinery; or of a naturally occurring material associated usually with limestone (rock asphalt), or with clay and sand (Trinidad Lake Asphalt), and also with tiny limestone shells (Boeton) or sandstone (Kyrock). (See also *Raw Materials*.)

Asphaltic bitumen has been defined by the International Committee (America disagreeing) (see *Nomenclature*) as: "Natural or naturally

occurring bitumen prepared from natural hydrocarbons or from derivatives of natural hydrocarbons by distillation or oxidation or cracking ; solid or viscous, containing a low percentage of volatile products ; possessing characteristic agglomerating properties, and substantially soluble in carbon disulphide."

This definition depends on the definition for 'Bitumen' (q.v.) whereby, out of the large number of substances covered by this term, only those capable of being used for the manufacture of asphalt come under the heading of 'asphaltic bitumen.'

The word 'substantially' is of significance. Bitumen is, by definition, completely soluble in carbon disulphide ; much asphaltic bitumen contains a fraction of a per cent. of matter insoluble in this solvent. Strictly, the presence of *any* insoluble matter changes an 'asphaltic bitumen' into an 'asphalt' (q.v.) ; but as this would be unpractical in the case of so small a quantity, a trifle of elbow-room has been given by the word 'substantially.' The wording of the standard definition of 'Asphalt' is : " Natural or mechanical mixtures in which the asphaltic bitumen is associated with inert mineral matter."

The *composition* of asphaltic bitumen is still being intensively investigated. From the chemical standpoint it consists of heavy oil, asphaltogenic acids (probably identical with the higher naphthenic acids) and anhydrides and lactones (derivatives of these), and gums and resins. From the standpoint of colloid chemistry, it consists of heavy oil carrying colloidal carbon produced by oxidation of the oil, and rendered stable by the presence of other components. (This subject is extremely complex, and need not be discussed further here ; see *Colloids and Emulsions* ; also ¹⁷ and particularly ²⁰².) Finally, from the physical chemistry standpoint of selective solvents, it consists of malthenes and asphaltenes (substances soluble in carbon disulphide, but the former being soluble and the latter insoluble in standard petroleum spirit), and occasionally carbenes (which are soluble in carbon disulphide and insoluble in carbon tetrachloride) ¹⁸. With risk of invidiousness it may be recorded that the names most closely connected with the deepest study of the *composition of bitumen* are J. E. Hackford ³⁶ of this country, and Dr. F. J. Nellensteyn of Holland. The subject is still being intensively examined, and a good summary of the more purely chemical side has recently been published ⁴⁹⁰.

The constituents of asphaltic bitumen are customarily classified as ⁷⁶ :

Oil, soluble in standard petroleum spirit, purified by fuller's earth ;
Hard Asphalt, insoluble in standard petroleum spirit ;

Soft Asphalt, soluble in ethyl ether, insoluble in ether-alcohol mixture ;

Paraffin wax, soluble in standard petroleum spirit, and separated by several partially satisfactory methods ;

Resin, usually estimated by difference, owing to change by oxidation during separation.

The separation by differential solvents is looked upon as resulting from a characteristic surface tension action of the various solvents on that colloidal mixture which is bitumen ¹⁷.

Calling hard asphalt by its older name of *asphaltenes*, the following are the compositions of some asphaltic bitumens, stated somewhat differently ¹⁹⁵ :

	Soft. Pt. R. & B. ° C.	Asphaltenes. %	Resins. %	Oil. %
Californian	50	6.89	44.16	48.95
Mexican	41	16.76	43.70	39.56
"	56	22.29	33.14	44.57
Roumanian	43	12.75	29.83	57.42
Polish	56	21.06	20.52	58.42
From Trinidad :				
Epuré	—	33.21	34.77	32.02
Venezuelan (blown)	60	19.61	25.76	54.63
Argentine	62	9.75	33.36	56.89

A deeper examination has revealed ¹⁸³ :

	%	C. %	H. %	S. %	O and N by diff. %
<i>Mexican Bitumen</i> : 170 pen.	—	82.93	10.37	6.20	0.50
Asphaltenes	18.60	83.45	7.37	8.83	0.35
Asphaltic Resins	19.44	81.56	9.70	7.15	0.59
Oil Resins	20.34	88.83	10.14	6.83	0.20
Oil	41.22	83.75	12.01	4.27	—
	99.60				

Sulphur may be present to over 5 per cent., as thiophen and thiophan and perhaps other substances. Nitrogen is present in quinolene and pyridine rings.

The study of the nature of asphaltenes is likely to lead to a much clearer understanding of the nature of bitumen. This is proceeding in the State Road Laboratory in The Hague, under its Director, Dr. F. J. Nellensteyn. The fact that the ether-soluble asphaltenes of Trinidad Lake asphalt contain the sulphur compounds, and that the oxygen compounds appear in the 'difference asphaltenes' (material insoluble in ether and petroleum spirit) gives a further glimpse of the

complexity of the subject ¹¹³. And later work has revealed, by means of chlorination, the presence of benzene rings in asphaltenes.

X-ray diffraction of many bitumens and related substances have yielded useful evaluations; and it has revealed that bitumens fulfilling certain specifications may still differ in their constitutions ⁵⁷⁸. This may throw valuable light on thixotropy. Rays beyond the other end of the spectrum, *infra-red rays*, have been found to produce in asphalt mixtures a hardening of the surface comparable to that which results during normal use ⁵⁷⁹.

Examination of *road oils* through their *dielectric constants* and their behaviour on solution has led to the conclusion that asphaltenes and resins are polar and that the oil constituents are non-polar, and that the asphaltenes are stabilized by the resins.

General chemical appearance is thus supported by detailed physical measurement—that flux oils should have as nearly as possible the same chemical nature as the material to be fluxed, in order that no change (or the very minimum) shall result beyond simple softening. At the same time, it has been claimed that anthracene oil flux greatly increases resistance to weather ⁴³⁵.

A valuable glimpse is obtained by ultra-filtration—the filtration of petroleum under pressure through membranes of nitro-cellulose or cellulose nitrate ⁷⁸. It was found that paraffin wax and resin exist in a state of true solution, and that the hard and soft asphalt are colloiddally dispersed and quantitatively removed by this process. This is contrary to the suggestion that the asphaltenes are dissolved in the resins and oily constituents ⁴³⁴, and that paraffin wax is present in the colloidal condition ⁴³⁶.

There appears to be so large a proportion of truth in all these conclusions, so that their final co-ordination is well worth undertaking.

Asphaltic bitumen is one of the most difficult and troublesome substances to investigate. A pure phenomenon is never met with; every observation has to be interpreted and understood as the result of complex influences, and desirable ideals in one direction have to be compromised by requirements in others.

It is opaque, and a non-conductor of electricity. It behaves like a plastic solid when hit gently, and like flint when struck hard. It ages slowly with time, so that the properties shown by bulk material at the beginning of an investigation will have changed before the end of it. Ageing is seen to be a more subtle and important matter than is usually recognized. It probably consists of three concurrent influences: atmospheric effect, probably slight, of light and oxidation; thixotropic change, slow evaporation (if any) and slow spontaneous chemical

change ; and slow change possibly accompanied by the crystallization of paraffin wax. The course of oxidation has been followed in Mexican bitumen of 457 pen. and residues from Gulf Coastal and Mid-continental crudes. Under a sun-lamp at about 77° C. all three absorbed oxygen, the resins and naphthenic oil rather more readily. Part of the oxygen was eliminated as water and carbon dioxide ; and all three showed an increase in weight ¹⁰⁷. The whole matter is further complicated by the rate of hardening being faster at the surface than at a small distance below it. When *heated* to its softening point and allowed to rest, it takes a year or more to return to its previous consistency. When heated for a prolonged period, even at only 120° C., hardening results that is out of all proportion to the small amount of volatile liquid lost ; ductility falls and penetration rises, unless the heating has been too drastic (say, for 27 hours at 194°), when penetration falls also. During such slow heating, the asphaltenes double their molecular weight. Prolonged heating at low temperature probably causes more change than short heating at an undesirable high temperature. The manufacturing temperature should be kept as low and for as short a time as is practicable ^{116, 117, 118}.

Grave errors of heating are still to be seen on the job, even though they can be easily recognized. If white vapours rise from the material, these will consist mainly of moisture ; but blue gases indicate the destruction of the bitumen.

There are two classes of substances present in asphaltic bitumen, combined sulphur and paraffin wax (and ceresin), which claim particular consideration, on account of the prolonged discussion on their effect on the material for road purposes.

Sulphur can be present in the asphaltic bitumen used for road making in this country in any amount up to 6 or 7 per cent. without being challenged, as there is still no certainty as to its effect, good or bad, on asphalt surfacing. It has been stated to be undesirable, on account of possible oxidation leading to the formation of acidic substances that might attack the mineral aggregate. It has also been said to be innocuous ; and finally, it is claimed that the higher the sulphur content, the more stable, the more adhesive, and the more desirable is the material.

Analysis has been standardized by the bromine method by the Institute of Petroleum (I.P.—61/45), but there is no difficulty in careful oxidation with nitric acid, saturated with bromine, and precipitation by barium sulphate.

Occasional reference is made to the vulcanizing action of the sulphur in the bitumen during and after any heat treatment it may undergo. This is based on analogy with rubber, and on the assumption that the sulphur is in the elemental condition ; whereas actually the sulphur

is already in combination and therefore most unlikely to exert any such action.

Paraffin Wax is normally present in asphaltic bitumen in varying proportions, and its effect is considered, on the whole, to be bad.

Although a small amount, up to 2 per cent., may be innocuous or may even be advantageous in aiding a high ductility, a larger amount certainly diminishes viscosity to an important extent, as is seen by the Table ⁵².

	Paraffin Content.	Soft. Pt. ° C.	Viscosity.	
			At 80°.	At 90°.
Mexican Bitumen	Trace	34	42	38
Good German Petr. Bitumen	1.5	35	55	20
Galician Petr. Residue	Abt. 4	33	6	3

It is not, therefore, surprising that adhesion also diminishes (see the following Table ⁵²), this being determined by the time taken for a small weight to adhere firmly to the material at 20° C.

	Paraffin Content.	Adhesion, in secs.
Mexican Bitumen	Trace	5
Good German Bitumen	1.5	10
" " "	1.5	40
" " "	1.8	63
Less Good Bitumen	4.5	120

If paraffin wax is present in proportions of more than 4 per cent., the material expands on cooling on account of the crystallization of the wax. The surface becomes rough, owing to the exudation of the wax during melting, diminishing the adhesion and laying it open to atmospheric attack ⁵³. At the same time, work in Germany has shown that, when properly treated, asphaltic bitumen, rich in paraffin wax, is not inferior for road purposes.

There is reason for considering paraffin wax to be not the homogeneous material usually assumed. There is crystallographic evidence to the contrary, which may explain certain difficulties in analysis ⁴²⁷.

Sources and Properties.

A broad division can be made in the types of asphaltic material used for road making in this country—natural asphalt and the asphaltic bitumen produced in the refinery. There is no inferential suggestion

that the one is superior to the other, though it must be recorded that the bitumen industry dislikes the term 'residual' as signifying something of little importance that has been left over : 'refinery bitumen' is a preferred term.

The *Rock Asphalt* used in this country is mainly limestone, impregnated with bitumen, from France, Italy or Switzerland. A sandstone asphalt (Kyrock) from Kentucky has been tried here ; but the Bituminous Sands of Alberta (Canada) have not arrived. The quality of the limestone asphalt may vary throughout a deposit of useful quality from 6 to 13 per cent., so that blending is practised to give the total percentage of bitumen required, and 'roasting' to produce equalized distribution of the bitumen. This may be 'fortified' by the addition of residual asphaltic bitumen ²⁵⁶, a decision which officially acknowledges a wide practice. There seems to be little known about the connection—and there must be one—between the natural grain of the mother-rock and the character of the resulting surfacing. The maximum permitted amount of clay present has been put at 2 per cent ²⁵⁶.

Lake Asphalt is represented solely by the Trinidad material, that from Bermuda not being imported.

In addition, there is asphalt from *Cuba* and from *Boeton*, both of which are of interesting composition and properties, but not used here.

The sources of *Refinery Asphaltic Bitumen*, prepared by distilling specially suitable types of petroleum, are fairly numerous.

A short account of these various raw materials follows, arranged so far as possible in the alphabetical order of their countries or origin ; but in a few cases clear trace of them is lost in their progress on to the road, and for this reason proprietary names have to be given. In nearly every case information about all these materials has been received from the producing firm.

Rock Asphalt. French. There are a number of deposits of asphalt rock in France, of which two are the more important.

Seyssel. Economic considerations alone prevent this material from being used for road purposes, so reference to it may be permitted, especially as the information respecting this source of rock asphalt is confused.

The composition of the rock is given ²¹¹ as being :

	%
Bitumen (S.p. 87° F. K. and S. Method)	8.00-8.15
Calcium Carbonate	89.55-91.30
Magnesium Carbonate	0.10
Iron and Aluminium Oxides	0.15
Insoluble in Acid	0.10-0.45
Water	1.9-0.0
Loss, etc.	0.10-0.20

An important source for road use is that of *St. Jean de Maruejols*, the sole concession of which, for Great Britain, is held by The French Asphalte Co., Ltd., amalgamated with Highways Construction, Ltd.

The French Asphalte Co., Ltd., was incorporated in October 1871, and laid its first compressed asphalt in Prince's Street, London, in 1872.

The deposits are situated about 100 metres below ground level.

The rock is a nearly pure limestone naturally impregnated with from 8–12 per cent. of bitumen. The following is a typical analysis :

	%
Bitumen	10.5
Calcium Carbonate	84.2
Magnesium Carbonate	2.8
Iron and Aluminium Oxides	1.6
Silica	0.4
Sulphur Trioxide	0.5
	<hr/> 100.0

The bitumen in the rock, after the material has gone through the various manufacturing processes, has the following properties :

Penetration, at 25° C.	about 100
Ductility, at 25° C.	+ 100
Viscosity, at 200° C.	5.9 Engler degrees.

German. A certain quantity of Limmer and Vorwohle asphalt once reached this country, mainly for use as mastic filler.

The content in bitumen is not high, and the material harder than most other rocks. Figs. IV.4 and IV.5 show views of surface mining of asphaltic rock.

Sicilian. Sicilian rock asphalt mines are owned by the Val de Travers Asphalte Paving Co., Ltd., and the material is marketed here by Messrs. Gatty Saunt & Co., representing the A.B.C.D. Co. of Italy. The mines, which are situated in the Ragusa zone of the Miocene limestone of Sicily, were first worked on a large scale in 1866.

Three qualities are available, graded according to the bitumen content :

- 10 per cent. for compressed asphalt ;
- 8–10 per cent. for compressed asphalt in warm climates and for mastic filler in cold ; and for blending ;
- 5–7 per cent. for mastic filler.

Above this, 12–20 per cent. rock is too irregular in its deposit for marketing, and is used for the extraction of bitumen and flux oil by retorting.



By the courtesy of the Val de Travers Asphalt Paving Co. Ltd.

FIG. IV.4.—Mines of the Limmer and Vorwohle Rock Asphalte Co. Ltd.



By the courtesy of the Val de Travers Asphalt Paving Co. Ltd.

FIG. IV.5.—Mines of the Limmer and Vorwohle Rock Asphalte Co. Ltd.

The composition of the 8–10 per cent. rock is as follows :

	%
Bitumen	9.24
Calcium Carbonate	87.98
Magnesium Carbonate	0.72
Iron and Aluminium Oxides	0.33
Silica	0.59
Water	0.96
Loss	0.18
	<hr/> 100.00

The chemical composition of the other grades differ from the above only in the bitumen content.

The bitumen has an s.p. 45–50° C.

A flux oil is obtained from the rock having the following properties :

Specific Gravity	0.971
Flash point, closed (Pensky-Marten)	145°
Viscosity (Engler), at 30° C.	39.6
" " 50	10
" " 70	4.8
" " 100	1.86

Swiss. Val de Travers. The sole concession for mining this material was originally granted to the Neuchatel Rock Asphalte Co., Ltd., a British firm. This firm has employed it for their roads, in this country only, since 1925 ; before this the sole concession for surfacing was in the hands of the Val de Travers Asphalte Paving Co., Ltd., which laid the first asphalt pavement in the City of London, in Threadneedle Street, in May 1869 ¹³⁵. Fig. IV.6 shows the manner of its mining.

The rock, which contains very little crystalline material, is evenly impregnated, and the following analyses may be given :

	%	%
Bitumen	9.00	10.15 ¹³²
Calcium Carbonate	89.70	88.40
Magnesium Carbonate	—	0.30
Silica	0.65	0.45
Iron and Aluminium Oxides	0.37	0.25
Magnesium Oxide	0.15	—
Calcium Sulphate	—	0.25
Loss, etc.	0.13	0.20
	<hr/> 100.00	<hr/> 100.00

The bitumen is somewhat soft, so that the rock is usually employed for blending with other rocks containing a harder bitumen. The normal heating process that the rock undergoes, involving a slight



By the courtesy of the Neuchâtel Rock Asphalt Co. Ltd.

FIG. IV.6.—Method of Mining Rock Asphalt.

loss of light oils with the moisture, in conjunction with the usual spontaneous hardening, leads to the following properties of the bitumen :

Softening point (Ball and Ring)	. . . . .	43° C.
Penetration, at 25° C.	. . . . .	150
Ductility, at 25° C.	. . . . .	+ 115 cm.

Trinidad Asphalt Lake. The Island of Trinidad was first discovered by Columbus, on his third voyage in 1498 ; but it was not till nearly 100 years later that Sir Walter Raleigh landed on the island,

in 1595, and recorded in his publication of 1596 the useful properties of 'stone pitch' found at La Brea, on the seashore : there is no reason for thinking he ever saw the lake itself ¹²⁹.

Great Britain took possession of the island in 1795. In 1851, the 10th Earl of Dundonald leased a portion of the lake for twenty years ; but it was only in 1876 that the first sheet asphalt pavement, consisting of Trinidad Lake Asphalt, sand, and mineral dust, was laid in Pennsylvania Avenue, Washington, as a result of the scientific work of the Belgian chemist, De Smedt.



By the courtesy of the Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. IV.7.—Typical View over the Trinidad Asphalt Lake.

Twenty years later, in 1895, the first streets of London were paved with the mixture—a portion of King's Road, Chelsea, and Pelham Street, Kensington. No great success was achieved, as the technical details were based on American experience, which the great difference of climate and traffic between England and America rendered invalid ; but experiments continued, and in 1908 the Victoria Embankment was paved with Trinidad asphalt, and the reputation of the material was established.

The lake lies in a bowl-like depression, at about 130 ft. above sea level, and has an area of about 100 acres. Its surface forms low mound-shaped masses, with water in the hollows ; and rank grass and vegetation grow in different parts (Fig. IV.7). The material is sufficiently solid to support men and trackways working on its surface and, at the same time, it is sufficiently plastic for a hole to disappear in 24 hours. Its maximum depth is about 285 ft., and the composition and quality

have been found, from the beginning of the industry, to be closely uniform throughout.

Refineries are situated at the edge of the lake, and refined and fluxed asphalt is shipped from La Brea, on the Gulf of Paria, opposite Venezuela.

Origin. The explanation commonly met with, to account for the intimate mixture of fine mineral aggregate with a bituminous semi-solid occurring in a crater-like depression, is that a basin caused by the bursting of a mud volcano through an oil field was filled afterwards with a mixture which slowly hardened.

Such a view leaves much geological evidence 'in the air,' and a different theory ³⁷³, made public here (in 1934) for the first time, brings the lake into geological perspective from being a somewhat vague and unique phenomenon.

It is now considered that the Trinidad Asphalt Lake originated as a surface extrusion of heavy bitumen in late Miocene times. Lowering of the earth's surface led to an incursion of the sea, and a deposit of silt and clay was laid over the inundated area. Part of this silt and clay penetrated the bitumen and saturated it, forming thereby a plastic mixture of silt, clay, bitumen, and water.

On subsequent elevation of the land surface above sea level, lateral pressure deformed the asphaltic mass into its present shape of a pseudolaccolite. Later, erosion gradually removed the cover, which ultimately collapsed, leaving the surface of the mass exposed: the island in the lake may well be a remnant of the original cover.

This theory asserts that the bitumen originates from the beds below the level of the formation of the lake, and in support of this is the occurrence of veins of pure bitumen in these lower beds. The mineral matter of the asphalt is ascribed to the same original source as the silts and clays which once covered and at present enclose the lake, and in support of this it can be shown that the two materials are identical.

The present hollow is due to the gradual exhaustion of its contents. The fact that the lake apparently loses less material than is taken out of it is explained as the result of the equilibrium of pressure between the semi-liquid mass and its surrounding and overlying strata. This equilibrium causes an inward and upward movement of the underground asphalt which partly compensates for the quantity removed. Accompanying this movement there is again a gradual sinking of the land surface.

Trinidad Lake Asphalt, having so outstanding a position in the road making world, is being treated here in rather full detail.

TRINIDAD LAKE ASPHALT AND FLUXED TRINIDAD LAKE ASPHALT: GENERAL SPECIFICATIONS

- A · Refined Trinidad Lake Asphalt (Epuré)
- B · Fluxed Trinidad Lake Asphalt Pen. 25
- C · Fluxed Trinidad Lake Asphalt Pen. 45
- D · Fluxed Trinidad Lake Asphalt Pen. 65
- E · Fluxed Trinidad Lake Asphalt Pen. 105

	A	B	C	D	E
Specific Gravity at 60° F.	1.40-1.42	1.29-1.31	1.28-1.30	1.25-1.28	1.19-1.21
Sol. in Trichlorethylene *	55.0-57.0% †	63.0-65.0%	64.0-66.0%	67.0-69.0%	69.5-71.5%
Mineral Ash	37.0-35.0%	31.5-29.5%	31.0-29.0%	29.0-27.0%	27.0-25.0%
Difference	8.0%	5.5%	5.0%	4.0%	3.5%
Softening point (R. and B.)	195-205° F.	142-147° F.	130-135° F.	120-125° F.	100-105° F.
Penetration at 77° F.	4	20-30	Not more than 1%	Not more than 1%	Not more than 1%
Loss after 5 hours at 220° F.	Trace	Not more than 1%	Not more than 3%	Not more than 3%	Not more than 5%
Loss after further 7 hours at 340° F.	1-2%	Not more than 3%	Not more than 5%	Not more than 5%	Not more than 5%
Loss in penetration	Nil	5	5-10	10-15	10-20
Ductility at 77° F.	1-2 cm.	25-30 cm.	45-55 cm.	55-70 cm.	90-100 cm.
Employed for	(Too hard for road construction.)	Mastic; hot-rolled asphalt for hot climates.	Normal hot-rolled asphalt.	Normal hot-rolled asphalt, specially base coat and high stone content and clinker asphalt.	Hot-rolled asphalt, in cold climates; surface dressing; admixed with filler (usually calcareous) for grouting.

* A non-inflammable substitute for carbon disulphide.

† The most extreme analytical figures vary between 52 to 58 per cent.

Before the War this material was being fluxed at the lake side and the various grades were sent out from there. Since the War this has been restarted, and a range of many steps, from 30 to 200 pen. is available.

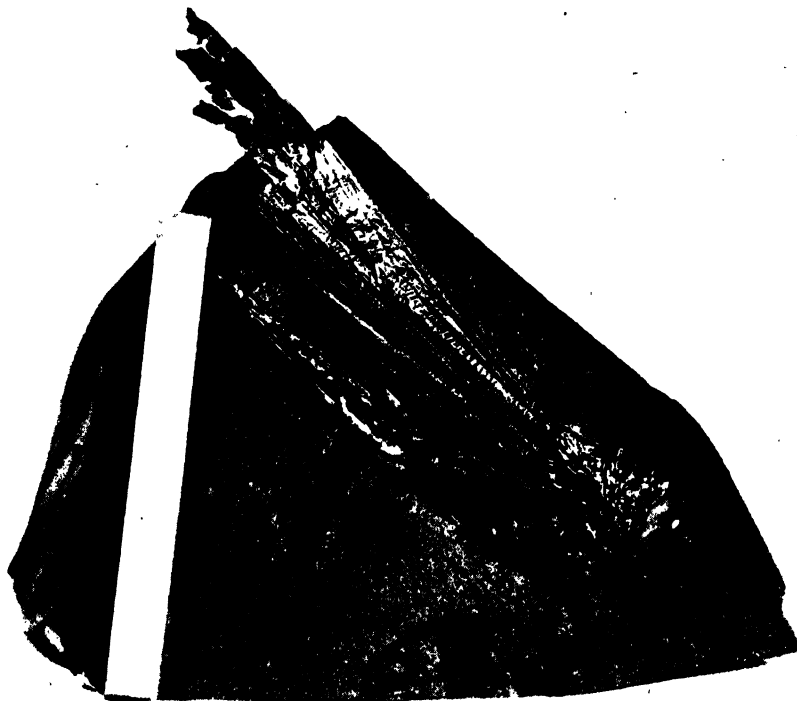
Composition and Properties.

A typical, freshly taken sample consists ¹³¹ of :

	%
Water and Gas, at 100° C.	29·0
Bitumen sol. in CS ₂	39·0
„ adsorbed by mineral matter	0·3
Mineral matter, on ignition	27·2
Water of hydration in mineral matter	4·3
	<hr/>
	99·8

(See also ¹⁹¹.)

The *grades of the road-making products* used before the war in this country are given in the Table (p. 103), the ‘*epuré*’ being the dehydrated raw material, strained through a $\frac{1}{8}$ -in. screen.



By the courtesy of the Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. IV.8.—This insect was found when a block of Trinidad Lake Asphalt was broken open in this country. It is a tropical American tree-haunting locust of the genus *Tropidacris* (order Orthoptera). It is about 5 in. long, and a good flyer. As there is no active animal life in the vicinity of the lake, it is possible that the insect may have fallen into a refining tank at the refinery on the coast.

(The size is indicated by the cigarette alongside.)

During the War, the Central Petroleum Pool sanctioned the following grades (July 1944) of the characteristics shown :

PROPERTIES OF EPURÉ/POOL 60-80 (PEN.) BITUMEN MIXTURES

Percentage Pool Bitumen.	0	10	20	30	40	50	60	70	80	100
PENETRATIONS										
@ 0° C. .	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	1	7
15° .	Nil	Nil	Nil	Nil	2	4	8	12	17	25
25° .	2	4	6	9	12	17	24	37	55	70
35° .	7	11	18	30	44	59	74	90	127	179
45° .	21	32	40	68	106	192	+ 250	+ 250	+ 250	+ 250
DUCTILITIES										
@ 0° C. .	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil	Nil
15° .	Nil	Nil	Nil	Nil	5	9	16	25	38	+ 100
25° .	Nil	Nil	Nil	9	15	29	40	55	63	+ 100
35° .	4	15	19	39	55	73	89	+ 100	+ 100	71
45° .	10	27	32	60	+ 100	+ 100	+ 100	+ 100	+ 100	Nil
SOFTENING POINTS (R. & B.)										
	89	84	80	75	71	67	62	58	55	47° C.
	192	183	176	167	160	153	144	136	131	117° F.
ASH (%)										
	35.8	32.6	27.2	25.1	21.6	18.4	15.8	11.4	7.8	0.2

PENETRATION AND DUCTILITY OF EPURÉ/POOL 180-220 (PEN.) MIXTURES

% Pool 180-220.	% Epuré	0° C.	15° C.	25° C.	35° C.	45° C.
PENETRATION						
0	100	Nil	Nil	2	7	21
10	90	Nil	Nil	5	16	34
20	80	Nil	3	10	25	52
30	70	Nil	8	17	35	95
40	60	Nil	13	30	63	163
50	50	2	18	41	104	250
60	40	3	24	59	154	—
70	30	6	33	74	191	—
80	20	10	49	120	—	—
90	10	15	53	155	—	—
100	0	20	61	200	—	—
DUCTILITY						
0	100	Nil	Nil	Nil	3	15
10	90	Nil	Nil	5	10	24
20	80	Nil	Nil	12	23	39
30	70	Nil	Nil	17	32	60
40	60	Nil	5	25	48	120 +
50	50	Nil	17	40	74	120 +
60	40	Nil	27	63	120 +	Nil
70	30	5	42	80	95	Nil
80	20	14	62	120 +	77	Nil
90	10	28	100	120 +	62	Nil
100	0	45	120 +	120 +	50	Nil

The average composition of the Lake *bitumen* to within less than 1 per cent. is :

		Malthenes ²⁵⁷ .	Asphaltenes ²⁵⁷ .
Carbon	82.33	54.14	28.19
Hydrogen	10.69	7.20	3.46
Sulphur	6.16	1.86	4.35
Nitrogen	0.81	0.80	—
	99.99	64.00	36.00

The usual differential solvents show the bitumen to consist of :

	%
Malthenes ; soluble in standard petroleum spirit .	62.0-64.0
Asphaltenes ; insoluble " " " .	37.0
Carbenes ; insoluble in carbon tetrachloride " .	0.0-1.3

There is about 9 per cent. of organic material that is not bitumen, such as 'peat acids,' vegetable matter, and wing cases of beetles, and, on one occasion, a whole insect was discovered (Fig. IV.8), as well as inorganic matter consisting of carbonized material, 'free carbon,' fragments of quartz and pyrites, sulphur, partially volatile salts, water of hydration and occluded gas.

The *mineral matter* in the asphalt consists of sharp flakes of quartz, and of clay, and some salts from the water originally emulsified in the crude bitumen. The composition is ¹⁸ :

	Mineral Matter. %			Finest Mineral Matter. %		
	Sol. in Acid.	Insol. in Acid.	Total.	Sol. in Acid.	Insol. in Acid.	Total.
Silica	—	70.64	70.64	—	32.36	32.36
Alumina	7.38	9.66	17.04	33.64	6.74	40.38
Ferric Oxide	6.30	1.32	7.62	11.74	1.40	13.14
Lime	0.46	0.24	0.70	3.20	0.45	3.65
Magnesia	0.11	0.79	0.90	1.40	0.34	1.74
Soda	1.56	—	1.56	0.53	—	0.53
Potassium Oxide	0.35	—	0.35	1.18	—	1.18
Sulphuric Oxide	0.97	—	0.97	7.16	—	7.16
Chlorine	0.22	—	0.22	—	—	—
Total	17.35	82.65	100.00	58.85	41.29	100.23

The grading of the mineral matter is :

passing 200 mesh 0.08 mm.	.	.	.	.	.	.	.	%
100 „ 0.17	.	.	.	.	.	.	.	89.8
80 „ 0.20	.	.	.	.	.	.	.	8.0
	.	.	.	.	.	.	.	2.2
								100.0

Elutriation of the material passing 200 mesh divided it into the following :

smaller than 0.08 mm.	.	.	.	.	.	.	.	%
0.05	.	.	.	.	.	.	.	24.3
0.025	.	.	.	.	.	.	.	13.1
0.0075	.	.	.	.	.	.	.	46.7
								15.9
								100.0

The *water* content is 29.0 per cent. on the crude asphalt, and contains the following substances ³², ³³ :

	Ref. 32. From the Lake.	Ref. 33. From the Refinery.
Specific Gravity	1.0599	
Solids, at 100° C.	82.100 g./kg.	
Sodium	27.193 „	6.5149 g./kg.
Potassium	0.528	0.3391
Chlorine	38.210	6.7757
Sulphuric Oxide	3.207	5.5409
Lime	Trace	0.5280 (Ca)
Magnesia	0.506	0.2666 (Mg)
Carbon Dioxide	3.700	
Silica	0.222	0.0688
Organic		0.4901
Sulphurous Oxide		0.0467
Sulphuretted Hydrogen		Trace
Sulphur		Trace
Boric Oxide		0.0117
Iodine		0.0008
Bromine		Trace
Ammonia		0.4071
Lithium		0.0271
Iron		0.0720
Aluminium		Trace
	73.566	21.0896

The associated *gas* is said to be a mixture of methane, carbon dioxide and sulphured hydrogen ³⁴; or of practically pure carbon dioxide ³³.

Other Natural Asphalts.

Cuban. It is composed of gilsonite and grahamite, materials classed as asphaltites. It is found associated with richly silicious mineral matter from the surface of the surrounding rocks, and with vegetable matter—wood and decayed vegetative.

It occurs in rocks of Cretaceous age; and is mined at Mariel, 30 miles from Havana, and shipped from Mariel Bay.

The composition of the powdered material prepared for use (which differs from that of the rock only by its matter volatile at 100° being reduced about 4 per cent.) is :

	%
Bitumen	51·45
Mineral matter	41·80
Organic matter	5·00
Volatile at 100° C.	1·75
	<hr/>
	100·00

The composition of the pure bitumen is :

	%
Malthenes (Petrolenes)	17·21
Asphaltenes	32·69
Carbenes	1·55
	<hr/>
	51·45

The material has had little popularity in this country, though it is well-known in America.

Boeton Asphalt is excavated in the island of that name in the Dutch East Indies. The material never got a footing in this country; it is used in Holland but more in Java, by the Boetenan and grit processes.

It consists of a hard bitumen, carrying in suspension minute calcareous shells of *globigerina* and their fragments, which give the asphalt a mineral matter naturally graded up to and including filter fineness. On this is based the claim of inherent toughness and non-skid properties.

Refinery Products : Texaco Petroleum Products are manufactured by the Texas Co., U.S.A., and distributed by the Texas Oil Co., Ltd.

This company first imported and used its products in Great Britain in 1915. The crude oil comes from wells in Texas and Mexico, and the bitumen is produced as the material of prime importance. As supplied it is classed amongst the blown bitumens.

Up to this point, all the information given has been obtained first

hand by the courtesy of the producers. In certain other directions there seems to be developing a feeling that so long as the purchaser obtains asphaltic bitumen to the specification agreed upon, it does not matter to him what is its origin. This is supported by the continuously developing refinery technique whereby a number of desired types of products can be produced from a number of differing types of crude oil ¹¹⁰.

It is this attitude of anonymity concerning the bitumen that has led to the following materials being described under the names of the marketing firms and not the source of the bitumen.

Shell-Mex and B.P., Ltd. Bitumen was first put on the market for road purposes by the Associates of this firm in 1910, and was then handled by the Anglo-Mexican Petroleum Co., Ltd.

At first the material was produced from *Mexican* and *Venezuelan* oils; the Mexican bitumen was imported as such, and that the Venezuelan oil is refined in this country. Their characteristics are as follows ¹⁰²:

Source.	Penetration.	Softening Point. (R. and B.). °C.	Asphaltenes.
Mexico	180-200	38-40.5	19
	125-150	45-46	—
	80-100	47-48	—
	60-70	51-52	—
	50-60	53-55	22
	40-50	56-58	23
	30-40	59-60.5	—
	20-30	62.5-64	—
	10-20	69-71	—
Venezuela	Av.	Av.	
	195	38	16
	135	44	—
	95	46	—
	65	50	—
	55	51.5	20
	45	55	21
	35	58	—
	25	61	—
	14	68	—

Later, political troubles stopped the importation of the Mexican bitumen; and during the War only Venezuelan bitumen arrived in the crude oil which was refined in this country. The grades sanctioned by the Central Petroleum Pool which was controlled by the Petroleum Board were, and are still, the following:

SPECIFICATIONS OF POOL GRADES OF ASPHALTIC BITUMEN

Grade.	Specific Gravity (@ 25°-25° C.	Softening Point (R. and B.)		Penetration (@ 25° C.	Ductility (@ 25° C.	Solubility in Carbon Disulphide. % wt.
		° C.	° F.			
180-220 pen. . .	1.00-1.05	35-41	95-106	180-220	100 min.	99 min.
60-80 pen. . .	1.00-1.05	47-53	116-127	60-80	100 "	99 "
15-25 pen. . .	1.01-1.06	60-71	140-160	15-25	5 "	99 "
80-90° C.M.P.*						
Hard . . .	1.02-1.07	80-90	176-194	5-15	0-6	99 "
110-120° C.M.P.*						
Hard . . .	1.05-1.10	110-120	230-248	1-5	0-1	99 "
Oxidized S . .	1.00-1.05	70-80	158-176	25-35	3 min.	99 "
Oxidized A . .	1.00-1.05	82-93	180-200	20-30	3 "	99 "
Oxidized B . .	1.00-1.05	110-121	230-250	10-20	2 "	99 "
Oxidized C . .	1.00-1.05	130-140	266-284	7-12	1 "	99 "
Mineral Rubber	1.00-1.05	149-160	300-320	2-8	0-2	99 "

* C.M.P. : C = Centigrade.

M.P. = Melting-point, an unjustifiable term in substitution for Softening point.

Anglo-American Oil Co., Ltd. The products of this firm first came on the market for road purposes in 1926. An excellent summary has been given by Dr. (now Professor) F. H. Garner ¹⁶³.

Flux Oils, Cut-backs, and Primers.

In certain processes in road making, especially in stone-coating and surface dressing, the asphaltic bitumen must be softened for the sake of handling at temperatures that are lower than those possible with the straight material. This can be done in two ways for two different purposes. The material can be *fluxed* with a relatively heavy oil which remains permanently in the mixture; or it can be *cut-back* with a relatively light oil, which slowly evaporates and allows the asphaltic bitumen to harden gradually to its original qualities, or very near them.

One characteristic of these liquids of over-riding importance is ability of forming a perfect mixture with the bitumen, a requirement which needs careful attention. On general chemical principles, the best diluent is one most nearly resembling the thicker liquid. It is justifiable to recall for analogy that water, H.OH , mixes completely with alcohol, $\text{C}_2\text{H}_5\text{OH}$, and incompletely with ether, $\text{C}_2\text{H}_5\text{OC}_2\text{H}_5$. Therefore, it is to be expected that fluxing or cutting-back asphaltic bitumen with anything but an asphaltic-base oil might not be satisfactory. The voice of industry is not unanimous on this point, but earlier opposition to paraffin-base oils seems to be disappearing.

For road making, the bitumen is usually of 100–200 pen. grade, and the properties and proportion of the lighter material are varied according to the final viscosity required. In one extreme case (see *Colprovia*) a mixture of solid bitumen powder and flux oil is used.

Flux Oils are only inferentially specified by the results desired by their use ; varying importance is attached to their volatility.

Cut-backs originated in America about 1920, where they have been greatly developed ³⁴⁰. The added oil may consist of kerosene, white spirit, or creosote. The mixture has been officially defined as having a penetration of 200 or over at 60° F. ³⁹⁷.

Cut-backs are used, hot or cold, for surface dressing (6–8 sq. yd./gal.), grouting, pre-mix or mix-in-place, after careful preparation of the dry surface.

Typical specifications of pre-war cut-backs are given in the following Table :

	Cut-back Bitumen for Surface Treatment.	Cut-back Bitumen for Grouting and for the Manufacture of Bituminous Macadam.
Specific Gravity at 60° F.	0.970–1.050	0.970–1.050
Viscosity, Hutchinson No. 2 poise, at 77°	10–75	50–125
Viscosity, B.R.T.A. at 77° F.	25–275	150–500
Flash point, Closed. Minimum	120° F.	120° F.
Water	Nil	Nil
Solubility in Carbon Disulphide	99.0%	99.0%
Volatile Distillate.	15–30%	15–30%
Asphaltic Bitumen	70–85%	70–85%

Cut-back bitumens using petroleum distillates usually show a specific gravity of 0.97–1.00, a higher figure indicates the presence of a coal tar distillate.

For viscosity measurements, the Redwood No. 2 at 140° F. and the Standard Tar Viscometer are both suitable instruments for use.

The tests put forward in America must be applied with caution in this country. This matter has been discussed in a most informative and constructive paper ³⁴⁷ to the World Petroleum Congress, in London in 1933.

The American classification into Rapid, Medium, and Slow Curing (or 'setting off' as we call it) is not generally adopted here, the tendency being to consider the materials from the point of view of the purpose for which they were being prepared.

To-day there are four Pool grades of cut-backs (see Table). No. 1 was originally intended as an all-purpose material, but it is now

used chiefly for stone-coating ; No. 1a is heavier, for summer conditions ; Nos. 2 and 3 are for spraying, of which No. 3 is non-toxic to fish. For some purposes these grades are used interchangeably, according to the temperatures desired in their use. Usually, stone-coating is carried out with the cut-back at about 250° F. and the stone at 100–200° F. ; and spraying from 200° to 300° F.

PETROLEUM BOARD CENTRAL BITUMEN POOL
SPECIFICATIONS OF POOL GRADES OF CUT-BACK BITUMENS (Nov. 1945)

	Pool Cut-back Bitumen.			
	No. 1.	No. 1a.	No. 2.	No. 3.
Specific Gravity @ 60° F.	0.98–1.03	0.98–1.03	0.98–1.03	0.98–1.03
Viscosity :				
Redwood Tar—				
@ 77° F. (25° C.)	270–340	—	135–205	135–205
@ 104° F. (40° C.)	—	85–105	—	—
Hutchinson No. 2—				
@ 77° F. (25° C.)	80–100	180–220	40–60	40–60
Flux Content, % wt. approx.	14	11.5	17	14
Bitumen Content, % wt. approx.	86	88.5	83	86
Solubility in Carbon Disulphide,				
% wt.	99 min.	99 min.	99 min.	99 min.
Mineral Matter (Ash), % wt.	1 max.	1 max.	1 max.	1 max.

Primers.

The use of these materials for assisting adhesion or entry of bituminous materials at the surface of smooth or finely porous surfaces is not general. They are used in certain cases of pre-mix work with emulsions and have been tried on concrete surfaces.

ROAD TAR

The International Definition for 'Tar' (see *Nomenclature*) runs as follows (America disagreeing): "A bituminous product, viscous or liquid, resulting from the destructive distillation of carbonaceous materials. The word 'tar' must always be preceded by the name of the matter from which it is produced: coal, shale, peat, vegetable matter, etc. Its mode of production should also be indicated." It consists of oils, intermediate and heavy resins, and insoluble carbonaceous matter united in the characteristically complex form of an 'associated colloid' ¹⁶⁰.

Pitch is, also officially, defined as a "Black or brown solid or semi-

solid fusible and cementitious residue remaining after partial evaporation or fractional distillation of tars or tar products."

Tar first *entered the road industry* ¹³⁴ in 1870 or earlier, but only more recently has it attempted to take its place as a binding material in surfacing to carry modern heavy traffic. It has had much leeway to make up in competition with asphalt, and research alone has enabled it to take its high and trusted position in the road world. This has resulted from the work which has been done by the gas companies, the tar distillers, and the Road Research Committee of the Department of Scientific and Industrial Research at the Road Research Laboratory. This has led to improvement in adhesion, reduction in bleeding in hot weather, and increased resistance against atmospheric attack. General road stability has been improved by increasingly higher viscosities and softening-points; and one factor in this progress is the virtual absence of naphthalene. (See also ³⁷¹.)

To-day, road tar is controlled by B.S. 76 : 1943, which divides it into three types, based not on viscosity but on road requirements, and these depend on the rate of setting on exposure.

A material made from the coal products resulting from low-temperature carbonization ⁵⁹⁸ has the following characteristics :

Sp. Gr. at 60° F.	. . . . .	1.047
Base Content, %	. . . . .	57.3
Viscosity at 68° F.	. . . . .	9.2° E.
Residue on Sieving	. . . . .	0.018 gr./100 mls.
pH Value .	. . . . .	9.26

The *chemical composition* of tar is better understood than is that of asphaltic bitumen ⁴⁵ as the substances present have been separated and identified with greater ease.

The highest value must be set on the presence of the 'free carbon' and its state of subdivision. It exists as relatively large and filterable particles, acting as a natural filler, as well as of far minuter ultra-particles which behave like those in asphaltic bitumen. (For formation, see ³⁵⁵.) This statement has been considered to be so abundantly true for so long that a shock was felt when recent experiments showed that 'free carbon' can be removed from a tar without affecting the viscosity—the characteristic and fundamental influence of a filler. It is now considered to be of no value for this purpose, but only one indication of the original and chemical properties of the tar. The coarse particles are claimed to give tar an inherent non-skid quality, which has little substantiation on direct evidence from the road. So critical is the influence of the 'free carbon' considered to be that in Holland a microscope count, giving the 'micron number' ^{25, 26}, is

made a basis for specification requirements. But although it has retained its position there, it has never been accepted as being suitable for tars in this country.

The chemical composition of 'free carbon' is suspected to vary according to the method of its separation, but it is approximately.

	%
Carbon	90.0
Hydrogen	3.5
Oxygen	4.0
Sulphur	1.5
Nitrogen	1.0
	<hr/>
	100.0

It is considered that the 'free carbon' not only acts physically by improving the consistency of the tar, but also chemically by increasing its resistance to atmospheric influences in thin films, when laid ³⁷.

The *physical constitution* of tar, elucidated by the examination of mean molecular weights, carbon hydrogen ratio, cryoscopic measurements, and the electron microscope, has been found to consist of particles of high molecular weight, surrounded by a layer of lower molecular weight, and suspended in an oily medium: with no sudden change between the inner and outer substances ⁴²⁵. Thus, the tar micelle is not very unlike that of asphaltic bitumen.

The problem of improving road tar by the solution of powdered coal in tar in order to increase similarity to asphaltic bitumen in certain properties has been the subject of a patent ²²⁵ by the South Metropolitan Gas Co.

It was found that a coal filler could be added to an amount of 40 per cent. (of the total weight of the mixture), and the resultant mixture could still be sprayed, after retaining its stability up to 25-30 km. journey in a spraying tank; sometimes addition of oil was advantageous. Limestone filler is less satisfactory. Experience obtained during 1932 and 1933 shows that the effect of climatic conditions is about the same with tar as with tar-bitumen mixtures. The economy in using coal or limestone filler in tar is 10-15 per cent., according to local conditions. A great deal of work has been done, mainly in France and Switzerland, on the effect of powdered coal and limestone as fillers for tar. The main result was the raising of the stability of the tar against temperature while retaining workability. In this country such a mixture of tar and coal filler is heated, so that there is some kind of semi-admixture of the two materials. (See also p. 84.)

Superficially, there are many similarities between tar and asphaltic bitumen; but scientifically, they are very different materials¹⁸⁵. This difference has been very carefully studied through the viscosities of the two classes of substances^{111, 112, 140}. Particularly, through the load-velocity relations (which depend on viscosity) it was shown that material even as hard as pitch is a true but highly viscous liquid, because the resulting velocity of movement is proportional to the load; and that asphaltic bitumen is a plastic solid, because the velocity is not proportional to the load.

The viscosity of tar is of the highest importance, of which the relation with temperature may be expressed as $t = a/v^m$, when t represents the temperature viscosity and a and m are constants depending on the type of the tar⁴⁰⁵.

It has, however, been stated on good authority, based on most careful work, that "although the viscosity forms an essential criterion for judging road tar, it is not universally valid for determining the extent of penetration and rate of setting"²¹⁷.

Further differences, that are commonly met with, are the rather sudden softening of tar, as compared with the slow softening of asphaltic bitumen; and the gradual surface hardening of tar due to evaporation and perhaps resinification of unsaturated components.

An interesting similarity of pitch with asphaltic bitumen is the hardening that results from prolonged heating at a relatively low temperature⁴⁰¹.

As in the case of most other road constructional matters, opinions differ as to the comparative desirability of tar of different origin to be used for tarmacadam. Usually, horizontal retort tar is much preferred, but vertical retort tar has been found to be satisfactorily amenable to distillation and blending, so as to remove as completely as possible naphthalene and 'creosote salts,' and to replace any lost creosote by anthracene oil.

The *manufacture* of road tars was formerly carried out by straight distillation of crude tar to give a residue of the required viscosity. This method has now been almost entirely superseded by the process of cutting back soft pitch with tar oil, thus giving better control over the setting and other properties of the product. The crude tar is distilled to give a residual soft pitch or base tar, which for all except the highest viscosity road-tars has a softening point of about 35° C. R. and B. (E.V.T. about 55° C.). The base tar is cut back with tar oil, the boiling range of which will control the type of road tar produced. For tars of type A with the most rapid setting properties, a fairly low boiling creosote, somewhat similar to that used for wood preservative, is suitable; for type C tars, with much slower setting properties,

a heavy oil of considerably higher boiling range is required. Oil for type B tars would be of intermediate boiling range. Typical boiling ranges are indicated in the following table :

	Oil for Type A Tars.	Oil for Type B Tars.	Oil for Type C. Tars.
Distillate to 200° C.	% 5 max.	% 3 max.	—
„ „ 260° C.	25-55	10-20	5 max.
„ „ 300° C.	40-70	30-40	20-30
„ „ 340° C.	—	60-70	45-65

Where tarmacadam manufacturers are only able to store one or perhaps two grades of tar, but require to make a proportion of their macadam in a form suitable for stocking, tar distillers can supply them with flux oil corresponding to the oil used in the preparation of tar so that the low viscosity tar necessary for producing macadam for storage can be made by the tarmacadam manufacture *in situ*.

The *hardening* of tar does not occur when stored and no loss by evaporation occurs. On the road a complicated phenomenon takes place. There is a slow spontaneous change of an ageing nature, superficially similar to that of asphaltic bitumen. Oils slowly evaporate; there is a slow oxidation, polymerization and resinification of unsaturated substances depending on the time of exposure, film thickness and other factors.

The factors concerned in the *underlying principles of the use* of tar for surfacing have been examined ⁴⁶. The tar acts as an adhesive, first wetting the stone and the road surface, and then changing into a tenaceous solid. This change results from cooling and evaporation, and not to any material extent from oxidation by the atmosphere. There is a close relation between the initial consistency of the tar, the temperature of application, with the size of aggregate held, and the extent of the surface to be wetted.

The *pollution of fish streams* has been continually before the Ministry of Agriculture and Fisheries ⁴⁷. It was originally considered that tar acids are the active poisoning agents, but it is later recognized that tar bases and other substances are also noxious. If, however, care be taken that phenols are absent or, if present, are in sufficiently low proportion, it may be assumed that other undesirable substances are also absent.

The whole matter was closely investigated by the South Metropolitan Gas Co. ³⁷, which found that all water-soluble constituents are

toxic to fish if undiluted, and toxicity increases with the boiling-point. Solubility, more than chemical composition, is the main factor; therefore, tar acids and tar bases are the most active.

Experiments have shown that tar products act directly in poisoning the fish, and indirectly by destroying their food. There is, however, a simmering doubt as to whether this contamination is as deadly under natural conditions as is made out; it has been denied in Germany. Evidence was put forward ²⁰⁶ that places responsibility for poisoning fish, at any rate in part, on the light oils present in tars and bituminous preparations. Such oils have been watched spreading over the surface of streams, and a small quantity of oil can cover a very large surface with a very thin but effective film; at the same time, this also has been authoritatively denied. The result is that the fish cannot get air, and flies are killed or kept out of reach; and in addition, as little as 0.001 per cent. of oil has been found ³⁴⁵ to prevent the growth of fish, and to dissolve their scales and cause bleeding.

The vociferous suspicion that has been attached to tar must not exclude the realization that fish are poisoned by other means also: excessive mud and peaty slime have been observed to be deadly ³²⁰.

The existence of *tar cancer* has long been known and official regulations and organized treatment are in operation. A cancerous condition can develop out of the preliminary warts and ulcers which may appear, but in the early stages such troubles are simply dealt with. Soap and water—personal cleanliness—is of the greatest importance.

Tar-Bitumen Mixtures.

“Why spoil good tar with bitumen?” was only asked by the diehards on each side.

Much careful investigation work on these mixtures has been published in Germany ^{20, 21, 22, 227, 238}, including a remarkably thorough investigation by Klinkmann ⁶¹, and also in Holland ^{23, 27}; but little in England ²⁴.

The claimed advantages of such mixtures were several and important. The ductility of the bitumen is combined with the penetrative qualities of the tar; the somewhat rapid softening and consequent ‘bleeding’ of the tar and its tendency to brittleness at low temperatures (susceptibility to temperature) are both lessened by the addition of bitumen; and the viscosity and adhesive qualities are increased, as well as resistance to weather.

Examples of the properties of tar-bitumen mixtures can be quoted:

	Spray Grade.	Grouting Grade.
Bitumen Content, %	73.5	80% min.
Specific Gravity, at 60° F.	1.0255	1.0300
Viscosity, Redwood No. 2, secs.	1,610 at 100° F.	550-700 at 140° F.
" Hutchinson, at 77° F., secs.	18	60
" Engler, at 212° F., secs.	107 (50 mm.)	—
Flash-point, Pensky-Marten, closed	198° F.	200° min.
Volatility, 50 g., 5 hours, 325° F.	17.05%	20% max.
Penetration of residue	132	—

Examples have been published of the remarkable difference in effect of Trinidad Lake Asphalt ²¹⁶ on tars of various origins but of the same original viscosity :

Epuré Content.	Sample A. Vertical Retort Tar.	Sample B. Horizontal Retort Tar.	Sample C. Coke Oven Tar.
Nil	25 secs.	25 secs.	25 secs.
5%	45 "	38 "	32 "
10%	68 "	51 "	40 "
15%	100 "	69 "	52 "
20%	150 "	102 "	69 "

For this reason ratio figures are used to give a general indication of this inter-relationship :

Added Trinidad Lake Asphalt.	Rise in Viscosity.
5%	to 2.5 times
10%	3.0
15%	3.5
20%	4.0
25%	5.0
30%	7.0

The advantage that has been found in the addition of fine material to tar-bitumen mixtures doubtless results from the restoration of the deficiency in free carbon caused by the dilution of the tar by the bitumen. This can be attained by the addition of 10 per cent. of powdered limestone, or it may be added in the form of Cuban asphalt. Furthermore, the higher temperature of use of the bitumen is lowered, and the possibility of a too-smooth surface is diminished.

At the same time, a firm that manufactures tar for tarmacadam, produced a material of high viscosity, and regarded the addition of bitumen to tar as being unnecessary.

There is a limit of about 15 per cent. to the amount of asphaltic

bitumen that could be added to tar for the mixture to retain its desirable qualities. Above this quantity, the binding properties of the mixture disappear; and loss of sheen, changes in viscosity and ductility, and a granular appearance under the microscope, all indicated that segregation within the mass has occurred. There was a similar limit at the other end: after the bitumen percentage has fallen from 100 to 85 through the addition of tar, segregation again began. Segregation appeared to be favoured, in an important degree, by the presence of high molecular compounds in the tar⁵⁹, and of the softer grades of bitumen⁶⁰. Further investigation advanced the safe proportion to 40 per cent. of bitumen in a mixture of 65 pen. Mexphalte and an 80-sec. viscosity tar; or 40-70 pen. Ebano bitumen and a specially selected tar. An addition of 7 per cent. limestone filler to the former mixture is stated to aid the degree of stability without being necessary to it.

The increase of the proportion of admixed bitumen was made possible by paying strict attention to the selection of the tar and the bitumen: their surface tensions should approximate as nearly as possible⁴⁸, and the 'free carbon,' which is removed from its sphere of action, by absorption in the clots of coagulated material, should be replaced. This is claimed to be fulfilled by Trinidad asphalt²⁴, whereby 70 per cent. of the asphalt, equivalent to 25 per cent. of bitumen, could be employed without segregation occurring. Boeton and Cuban asphalts both claim complete and satisfactory mixture in all proportions, the latter asphalt through its content in asphaltite.

Thus it is seen that the prime factors in the permanence of such mixtures are physical, in so far as they are mixtures of colloidal systems complicated by partial solution of certain constituent substances; chemical action either does not take place or has no effect on segregation.

Investigation has been hampered by the imperfection of existing methods of chemical analysis. All except two depend on the action of sulphuric acid rendering the tar soluble in water and leaving the bitumen untouched. With mixture of many tars and bitumens, in limited proportions, such a method works well, but with British tars difficulties of filtering occur. The dimethyl sulphate separation is definitely unreliable³¹³, and Nellensteyn's differential solvent (based on surface tension methods) was rather slow, but it could be used with mixtures containing as much as 50 per cent. bitumen. A valuable discussion⁴⁵⁰ on the whole matter took place at the World Petroleum Congress, London, in 1933, and a resolution was passed calling for further work to be done for a final conclusion to be reached. Much excellent work has been done in the development of these mixtures.

Experience has lead to a greatly diminished demand for them, but investigations in the laboratory and on the road are continuing. In the Tarmacadam Specification of 1945, the proportion of tar and bitumen to be used is to be settled between the manufacturer and purchaser.

The *addition of resin* to tar and bitumen causes advantageous changes in ductility, rise of softening point, adhesion and covering-power, and plasticity. Viscosity is increased and capillary rise is diminished. Two parts of metallic resins are found to be equivalent in effect to 3 parts of resin ⁵¹⁸.

COLLOIDS AND EMULSIONS

Colloids

Theoretical. The word 'colloid,' together with its companion 'crystalloid,' has been used ever since Graham (1861-4) invented them both to indicate two classes of solid substances whose behaviour is so profoundly different. They are represented characteristically by the materials glue and common salt.

A colloid may be described to-day as being a substance in so fine a state of subdivision that it no longer obeys the normal mechanical and physical laws, such as settling under gravity, and is possessed of great surface activity.

The first use of an emulsion for road purposes is claimed by L. S. Van Westrum, who employed an emulsion of crude asphaltic-base oil for laying dust in 1900. To-day emulsions are used for firmly binding together the major elements of a road surfacing: practical experience began here in 1911, it rapidly developed about 1923, and spread to Germany about 1926.

Far-reaching and difficult researches have elucidated the extraordinary change in properties that matter undergoes when it becomes more and more finely subdivided, until it passes through the finest filter papers and can be identified even in the ultra-microscope only as points of light. The significance of this subdivision is the enormous increase of surface area that results: if a cubic centimetre of a substance be regularly divided into cubes until the length of their sides has been reduced from 1 cm. to $\frac{1}{1000}$ mm. (1μ), the surface area has been increased to 6 sq. metres. The properties of colloidal materials and mixtures depend primarily on such extreme minuteness of the particles (or, what is the same thing, the relatively enormous area of surface compared with its mass) which ultimately approaches the size of large molecules. Thus, extreme subdivision and diminution in size of a liquid or solid leads a suspension of such a material in liquid to exist

in a condition intermediate between a true mixture and a true solution. It is customary to call dispersions greater than $0.1\ \mu$ 'coarse'; colloids range from $0.1\ \mu$ to $1.0\ \mu\mu$, and finer particles than this are known as 'molecular dispersions' or 'amicrons.' ($1\ \mu$ is 1 micron, which is $\frac{1}{1000}$ mm., $1\ \mu\mu$ is a millimicron, or millionth mm.)

These inter-relations can be understood more clearly when set out as follows :

	Visibility Field (Approx.).	Length of Side of Cube.	Number of Cubes.	Total Surface Area.
Coarse Dispersions.	Visible to eye . . . {	1.0 cm.	1	6 sq. cm.
		1.0 mm.	10^3	60 "
		0.1 "	10^6	600 "
	Visible in microscope {	0.01 "	10^9	6,000 "
		$1.0\ \mu$	10^{12}	6 sq. m.
Colloids.	Invisible in microscope, visible in ultramicroscope {	$0.1\ \mu$ } approx. 5 {	10^{15}	60 "
		$0.01\ \mu$ } $\mu\mu$ {	10^{18}	600 "
Molecular Dispersions.	Invisible in ultramicroscope {	$1.0\ \mu\mu$	10^{21}	6,000 "
		$0.1\ \mu\mu$	10^{24}	60,000 "
		$0.01\ \mu\mu$	10^{27}	600,000 "
		$0.001\ \mu\mu$	10^{30}	6 sq. km.

The determination of the number of particles of successive limits of size, and of the average diameter of particle size, in emulsions has been described in an easily available publication ³⁸¹.

There is a peculiarity associated with surfaces known as *surface tension*. This is primarily due to every molecule at a surface being attracted by its fellows on each side and below it, but not above, where there are none. This gives rise to the formation of a kind of mobile skin, one molecule thick, easily investigated in liquids, but very difficult to examine in solids.

When two surfaces touch, as in the case of a liquid and a solid, the interaction—adhesion, and penetration of pores—varies quantitatively according to the nature of the liquid and the solid. The physical occurrences at the contact of two such surfaces are so complicated that they have not yet been fully elucidated; they are known to be partly electrical in nature, but for present purposes it is enough to know that their final external expression is what is known as *adhesion*. (See also ^{17, 114, 115}.)

A further interaction occurs at the surface of some pairs of materials

known as *adsorption*, which is less than absorption and more than adhesion—less of a soaking into the surface layers of a solid and more than a simple surface-to-surface attraction. There appears to be a definite reaction between the molecules of the surfaces of both substances, in which both chemistry and physics are concerned.

Emulsions

(*Note.*—Particular attention is called to the Papers on the properties and testing of Emulsions that were read and discussed before the World Petroleum Congress, held in London, in 1933 ⁴⁵⁴, and at the International Roads Congresses, Munich, 1934, and The Hague, 1938. (See also ³⁵¹, ⁹⁷, ¹⁹⁸, ¹⁹⁹; and the excellent volume on *Road Emulsions*.)

Nature and Formation of Emulsions. The two chief properties of fundamental interest in an emulsion, which may be *defined* as a suspension of a finely subdivided liquid in another liquid, are (1) the greatly diminished effect of gravity, and (2) the development at the surface of each liquid particle of surface energy.

(1) The approach of the disperse (subdivided) phase towards the dimensions of a molecule leads to an increasing helplessness towards the buffering received from the rapidly moving molecules of the continuous phase (the surrounding liquid). This leads to an increasing tendency of the subdivided material to remain in suspension and not to settle out, a tendency greatly assisted when there exists a close similarity in specific gravity of the two liquids, and, in a less degree, by the viscosity of the surrounding liquid.

(2) The energy developed at the surface of contact of two materials is of two kinds. Firstly, there is surface tension. One effect of this is to tend to cause the suspended particles to draw together and agglomerate, and is, therefore, a force acting against stability. At the same time there exists a counterbalancing action of repulsion caused by the negative electric charges carried by the globules. This mutual repulsion is sustained by the presence of alkalis in the emulsion (hence the use of alkaline stabilizers); it is the disturbance of this electric charge by acids or salts in water that tends to destroy an emulsion ²⁰⁸.

To improve and control the stability of an emulsion, a substance is added—itsself a colloid—known as the ‘emulsifier.’ By virtue of the drop in surface tension this material concentrates at the interface of the two phases, and even a thickness of a few molecules tends to cause a physical isolation between them. The emulsifier is to be differentiated from the ‘stabilizer,’ which is a substance added to a dispersion already made.

The considerations so far given have been of the oil-in-water type

of emulsion, but water-in-oil emulsions also exist. These were developed, particularly in France, for road purposes, with tar, but they soon disappeared.

Breaking of Emulsions. The conditions just described for the formation of emulsions in the works and for their stabilization during storage—namely, desired fineness of division, diminution of surface tension, and preservation of electrical charges on the particles, together with suitable degree of concentration—have to be reversed when the time comes for the emulsion to break, for the formation of a cohesive layer of asphalt.

The behaviour of road emulsions is considered on page 130, and under *Testing*.

Road Emulsions ¹⁵⁷.

These may be defined as a liquid product in which a substantial amount of asphaltic bitumen or tar is kept suspended in a finely divided condition in an aqueous medium by means of one or more suitable emulsifying agents (B.B.S. 434 : 1935, slightly modified). They were first laid in 1913, and the modern type was launched in 1923.

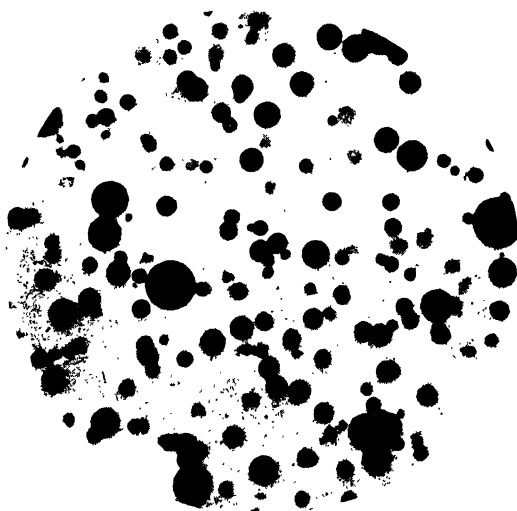
The prime object of a road emulsion is the distribution of a bituminous material over and into a road surface by means of an aqueous vehicle, which deposits its burden and disappears. In order that this should occur in the right place and at the right time and produce the desired result, care must be taken with the preparation of the road surface, and great care with the preparation, choice (summer or winter grade), and application of the emulsion. Thus, it is clearly seen that the breaking of an emulsion is the result of a complex of sensitive conditions and influences.

Road emulsions are made in three grades: the quick-breaking type are used for general road purposes; slow-breaking emulsions are used with finer aggregate, and for grouting where breaking is to be retarded till penetration is completed; stable emulsions are used with fine aggregate and for soil stabilization. These differences in behaviour result from the nature of the emulsifying agent chosen.

Asphaltic Bitumen. Emulsions made with this material are governed by B.S. 434 : 1935. The specification is a simple one; the only noteworthy points being that the viscosity is to be measured by an Engler viscometer (as being the most suitable owing to its warmed orifice); that the proportion of emulsifying agent, although limited to 1 per cent. of the weight of the emulsion, has no prescribed method of estimation; and the lability test, which is of much importance in determining the rate of break of an emulsion and thereby an important link between composition and behaviour.

The appearance of a typical road emulsion, under high magnification, is seen in Fig. IV.9. These emulsions are not very difficult to prepare, one reason being that the specific gravity of the material is near to that of water, so that there is little tendency to rise or sink : an exception to this is Trinidad asphalt. The harder the grade, the more difficult it is to emulsify, but this does not prevent successful preparation when required.

As a rule, road emulsions contain 50–60 or even 66 per cent. of asphaltic bitumen ; but emulsions can successfully be made with 80 per cent. or even more of the bitumen, though these are not suitable for immediate use on the road, and cannot always be diluted without damage.



By the courtesy of Colas Products, Ltd.

FIG. IV.9.—Typical Standard Road Emulsion made with Asphaltic Bitumen. $\times 700$.

Tar. The higher surface tension and specific gravity of tar makes it more difficult to emulsify, but these influences are counter-balanced to a certain degree by the emulsifying tendencies of some of the constituents of the tar.

Tar emulsions are controlled by B.S. 618 : 1935 ; and although their position is improving—there are several in use—no important

change in technique has so far justified revision. They may contain not more than 20 per cent. asphaltic bitumen ; and on account of the nature of the material to be kept in suspension, the proportion of emulsifier is raised to 2 per cent. A reliable breaking test is still being sought.

In general, the use of tar emulsions requires a higher percentage of binding material in the road surface. There are fewer tar emulsions on the market and, therefore, fewer examples to generalize from. Considerable secrecy is preserved concerning tar emulsions ; the following table gives details of two pre-war and pre-specification examples.

One (French) emulsion, containing 90–95 per cent. of tar, is stiff when cold and has to be heated to 60–80° C. and diluted with water at the same temperature to a 30–75 per cent. emulsion before use. The interest in this type is that it is the reverse of an ordinary road emulsion,

	A.	B.
Grades	No. 2 : surfacing and coating stone No. 3 : grouting and patching	Summer, winter, and tropical grades, for surface dressing, grouting, and curing of concrete
Proportion of Tar . .	60% of 90% tar + 10% asphaltic bitumen	70% tar
Properties of Tar . .	British Standard Specification	British Standard Specification Tar Nos. 2 and 3
Stabilizer	Mixed, totalling 1%	—
Viscosity, ° Engler . .	6-10	5-10
Average quantity required for surface dressing	0.2 gal./sq. yd.	Abt. 0.2 gal./sq. yd.
Ditto for full grouting .	3-in. coat : 1½-2 gal./sq. yd.	(Conditions uncertain) 2-3 gal./sq. yd.
Mixer	Neither paddle nor colloid mill	Colloid mill type

in that the tar is the external or continuous phase and the water the disperse phase. The added water acts rather as a softener than as a diluent for the emulsion ; it is absorbed when warm and given up on cooling. Through this curious condition, the emulsion cannot be washed away by rain.

Stabilizers and Emulsifiers. The diversity of materials suggested and employed is remarkable but, except for the alkalis, they are all of the same general class : they are themselves colloids or possess colloids as their active component.

Alkalis, or substances yielding alkalis and other co-operating substances when in contact with water, are an important set of emulsifiers. They may be in the form of simple alkalis, such as hydroxides or carbonates of sodium, potassium, or ammonium ; or they may be simple or rosin soaps which supply an alkali and an acid colloid in contact with water. Also, sodium silicate (water glass) yields soda and colloidal silicic acid ; and it is probable that when clay is used it acts not only mechanically but also through a similar but slight decomposition.

Organic bases—weak alkalis, but still alkalis—such as pyridine, piccoline, and quinoline, are quoted as having been used. Saponin, glue, the gums, pectin and vegetable mucilages, sulphite (paper) liquors, waste molasses liquors, starch, Irish moss, and casein, are all essentially protective colloids. In addition, vegetable oils acted on by sulphuric acid (Turkey Red Oil), and also rubber latex, have been used.

In some cases the emulsifier is produced indirectly. The material

to be emulsified is mixed with a fatty acid or naphthenic acid (the latter may be present naturally) and alkali added with the water, when a desired soap is formed.

The choice of the emulsifier to be used is in a considerable degree controlled by the idiosyncrasy of the material to be treated and the purpose of the emulsion to be produced.

In use, the emulsifier must be present in as small a proportion as possible, partly to avoid the possibility of re-emulsification under traffic, and partly to avoid any possibility of diminishing the adhesive power of the bitumen to the mineral matter of the road surface. As a rule, the degree of sub-division is very largely dependent on the quantity of emulsifier present. Multiple stabilizers are employed.

Water. Practical experience shows the effect of dissolved salts in water, both in the manufacture of emulsions and their breaking on the road, to be extremely variable. In some cases it is slight; in others it is most disturbing; in others again, the emulsion can be modified to permit the employment of even brackish water. Broadly speaking, dissolved salts affect the electric charges on the suspended particles to a degree sufficient to destroy or even reverse the colloid system. Organic matter tends to counteract the action of the emulsifier, so that the pouring of an emulsion on to a road surface already wet with dirty water may easily lead to irregular results.

The behaviour of the water of the poured emulsion is varied and complex. Some evaporates, some is filtered out and flows away, and some enters the pores of the porous mineral aggregate or settles in the minute irregularities of its surface.

Manufacture.

Two general methods are employed: the older batch mixer and the later high-speed colloidal mill. The former produces emulsification by the rotation of paddles from 30 to 1,000 r.p.m., and the latter by passing the mixture, by pressure and centrifugal force between two plates, one rotating at high speed, with a clearance of 5 to 25 thousandths of an inch. Automatic control enables the nature of the product to be easily regulated. (See also ⁴⁰⁰.)

Sampling and Tests. These, for the emulsion and for the bitumen employed, are regulated by B.S. 434 : 1935.

The *nature of the stabilizer* is of crucial importance. Apart from proprietary articles, soap of some kind, such as sodium oleate or resinate, is usually employed. Not more than 1 per cent. is usually employed (which is half the upper limit of the British Standard Specification), and sometimes as little as 0.15 per cent. Casein is used when stable and slow-breaking emulsions are required.

The *viscosity* of emulsions is another vitally important matter, as this controls depth of penetration on application : grouting emulsions having a lower viscosity than those for surface dressing. A high viscosity is of advantage in reducing the flow of emulsion down the camber of the road. The German Engler viscometer is employed in this country as being the most suitable of any.

For grouting, 3–8° Engler (but see British Standard Specification) are usual, and 4–12° for surface dressing ; for heavy mix emulsion, 15–20° E. may be found. All these measurements are at 20° C.

It has not been the intention in this book to discuss the patents that both protect and involve the emulsion section of the road industry : they are of ever-growing complexity.

There is, however, one patent ³⁴⁶ of such outstanding scientific value, though its technical importance was insufficiently appreciated. There was a growing desire to increase the viscosity of the bitumen emulsion, and the only way of doing this was to increase the bitumen content or to increase or modify the emulsifier or stabilizer—and this is not always desirable. As a result, however, of highly scientific work and keen observation success was attained in a most unexpected manner—by mixing with the bituminous component a limited amount of a water-soluble substance so that, after the emulsion has been formed, this material which became included within the particles of bitumen attracted water to itself, caused them to swell, and so to increase the viscosity of the emulsion as a whole. The great value of this work lies in the opening of the way to the control of emulsion viscosity without variation of bitumen content.

An ever-increasing knowledge of the nature and behaviour of emulsions has resulted from an excellent example of collaboration between the various component firms of the Road Emulsion and Cold Bituminous Roads Association. After a great deal of most careful work, the behaviour of emulsions during coagulation and setting have become clearer ; and conclusions arrived at are ⁸⁴ :

“ 1. Normal types of road emulsions all give evaporation curves of the same general form, with an initial rate of evaporation approximating to that of the free aqueous phase ; with the incidence of coagulation the rate of evaporation decreases sharply, and the range of residual water contents over which this change occurs may vary considerably from one emulsion to another.

2. During drying, emulsions pass through several distinct stages before the final adhesive film of binder is produced, and in some circumstances there may be a period during which the emulsion residues have very little mechanical strength and poor adhesive

qualities—a condition which, in practice, is likely to give rise to the so-called ‘non-adhesive set.’

3. The mechanical properties of the emulsion residues are largely determined by the consistency of the binder at the drying temperature and are little influenced by the type of the emulsifier used or the rate of drying; the non-ductile residues of poor binding power which tend to be formed at winter temperatures may be avoided by suitably softening the binder.

4. The range of residual water contents over which coagulation occurs by evaporation is controlled mainly by the composition of the emulsifier, particularly at low temperatures, but is also influenced appreciably by the consistency of the binder and, to a relatively slight extent, by the dispersion of the binder and the rate of drying.

5. From the results so far obtained, sodium soap emulsifiers appear to cause coagulation at higher residual water contents than potassium soap. This effect, which is considerably enhanced by the use of soft binders, is very marked at low temperatures and may be accompanied by the separation of a macroscopic aqueous film between the film of binder and the underlying surface; complete drying and adhesion of the binder are thereby seriously delayed. This condition appears also, in certain circumstances, to be induced by the presence of an excessive amount of free alkali.

6. It follows from conclusions 3 and 5 that, in using a soft binder to improve the mechanical properties of emulsion residues at low temperatures, an appropriate emulsifier must be used. In certain circumstances sodium soap emulsifiers may be unsuitable, while undue proportions of free alkali are to be avoided.”

Application. (An accurate, commentative, but frankly propaganda account has summarized the position ³⁵¹.)

This consists of two parts—the preparation and laying of the road metal, and the application of the emulsion (see B.S. 433 : 1931).

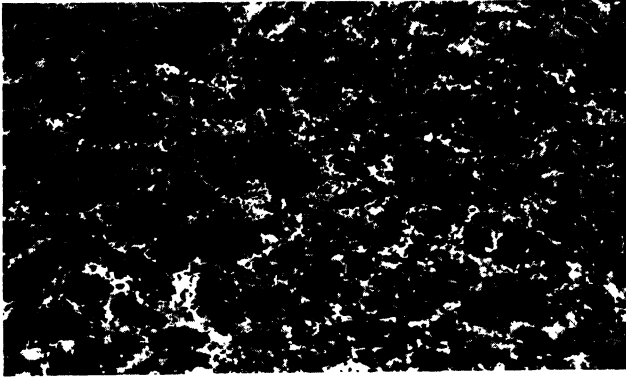
Details are given elsewhere ^{196, 381}, so that only a few points need be emphasized here.

In the preparation of the road surface, it is highly important that dust and mud shall be removed as completely as possible. The quantity of dust left on the surface to be treated will be the measure of the non-adhering dust-and-binder ‘cheese’ that will be produced. In Wandsworth, for instance, where emulsions have been successful, preliminary sweeping is carried out first with an African bass broom and then with a fine hair broom.

Emulsions are sometimes used hot, either to reduce viscosity or to accelerate setting, to facilitate use in cold weather, or incidental to

production in wayside plants (which have to-day become obsolete). As a technical development this is of no great importance.

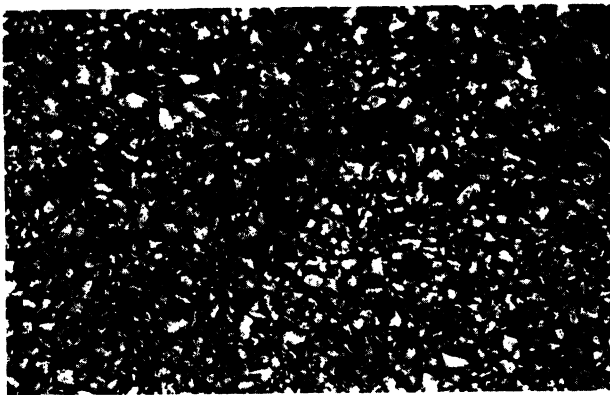
The emulsions are applied by pouring or spraying out of containers varying from the size of a watering can to a travelling tank, the latter



By the courtesy of Dussek Bitumen and Taroleum, Ltd.

FIG. IV.10.— $\frac{3}{4}$ -in. Chippings held by Emulsion.

discharging at a rate proportional to its speed of travel. The quantity required varies with the material and very much with the local requirements of traffic and topographical conditions.



By the courtesy of Dussek Bitumen and Taroleum, Ltd.

FIG. IV.11.— $\frac{1}{4}$ -in. Chippings held by Emulsion.

Chippings should be spread and rolled in soon after the application of the emulsion, as this not only assists consolidation, but also the breaking of the emulsion; and rolling must be as thorough as with hot asphalt. Figs. IV.10 and IV.11 show examples of such surface dressings.

The *quantity of emulsion* used naturally varies with the nature of the surface treated, and is indicated in the British Standard Specification 433 : 1931.

There is no such regularity between the quantity and quality of the emulsion and the size of chippings held, beyond small chippings requiring less emulsion than larger : it is a matter mainly of viscosity of the separated bitumen.

In all bitumen-aggregate relationships limestones are found to bind better than granite, and the following supporting figures for an emulsion with the same quantity of the same grading of rock are illuminating ³³⁹ :

Limestone	.	.	.	.	.	.	.	4½% bitumen
Granite	.	.	.	.	.	.	.	7½ „ „
Whin	.	.	.	.	.	.	.	7½ „ „

The *breaking* of emulsions on the road is a complicated phenomenon, still with irregularities which require detailed study. Coagulation results mainly from loss of water which depends on conditions of temperature, humidity and velocity of movements of air, and local situation. It is aided by absorption into the dry aggregate. Breaking may be assisted by the chemical character of the stone from which acid or alkaline ions may be given off (as in the case of slag and limestone), or these may be derived from solutes in the water employed. But there is a discrepancy here as basalt is a more effective precipitator than limestone. Coagulation is also assisted by adsorption of the emulsifier by the stone, whereby it is withdrawn from its function of preserving the emulsion. Also, the finer the mineral aggregate the quicker is the break of the emulsion ; and, finally, coagulation is encouraged by mechanical disturbance such as the passage of a roller or of traffic.

Adhesion. Experience with the classical hot asphalt makes puzzling the possibility of adhesion of bitumen particles with wet aggregate. In fact, stripping of a newly deposited film from its support was a serious technical difficulty. This separation could occur during any movement of the mass before it had completely dried out, whether by the action of a shovel on the pile of premixed material, or by a roller passing over a laid surfacing. Rolling must be done before the beginning or after the end of the breaking of the emulsion—at an intermediate stage, stripping will result.

Surface dressing with emulsions can be employed with several different aims : such emulsions containing 60–65 per cent. of bitumen are usual, though those containing about 55 per cent. are also used. The strengthening and sealing of macadam, both water- and tar-bound,

is well known. The life of wood paving often can be considerably prolonged by use of emulsions and chippings, which not only seal the joints, but also provide a wearing surface. They should not be applied until the surplus creosote has dispersed. If the treatment is repeated at intervals—usually every second year is sufficient—there results a cushion of bitumen and chippings, a firm and 'live' wearing surface relieving the wood blocks of all abrasion. But the advantages of surface treatment are lost if the accumulated layers become too thick, when they tend to roll up.

Stone setts have been rendered less noisy, and given a more even wearing surface, by treatment with an emulsion, but here the difficult problem of adhesion may sometimes have to be solved by means of the application of a 'fixer' to the setts before the emulsion is applied.

The desire for the surface treatment of concrete gives rise to a problem that the emulsion manufacturers have not yet satisfactorily solved; as up to the present adhesion is usually poor and wear is considerable after a few months. The expansion joints in concrete roads have been successfully filled with sand and bitumen emulsion.

Grouting is employed for the consolidation of macadam, and of earth and cinder paths. The emulsion usually contains 63–65 per cent. of bitumen; 57 per cent. is also used.

The following is an interesting and remarkable example of the usefulness of emulsions. One winter, when covered with snow, the 2-in. mastic asphalt surface in Trinity Road, Wandsworth, broke up into small pieces, after it had been down less than a year. Water found its way underneath, and was squelching up between the fragments as traffic passed over. It appeared to be useless as a road surface, and the weather was too bad for it to be relaid. In the hope that it might hold together until conditions were more favourable for replacement, surface dressing with emulsion was tried. The result was so successful that it was allowed to remain and, some 16 years after the event, the road, which has received further dressings from time to time, was still in good condition. Its peace-time load was over 10,000 tons per day, including an omnibus service and considerable proportions of heavy traffic.

The asphalt was opened up for examination, before the end of the first 6 years, after it had carried over 18 million tons of traffic, and it was found that the emulsion had joined together the upper half of the asphalt crust, but that the lower half of the pieces was still unconnected (Fig. IV.12). The film of mud which, in its original condition, had separated the pieces for the full depth, extended about half-way through the crust from the bottom. Fig. IV.13 shows one of a series of samples of the asphalt, about 18 in. square, cut at random from the

road and re-broken on the lines of the old cracks. All the samples were similar and represented the condition of the portion of the road about 200 yd. in length by 24 ft. in width, which had broken up.



FIG. IV.12.—Fig. IV.13 seen in Section, showing Depth of Penetration by Emulsion.

- A. Bitumen emulsion joint.
- B. Open joint, mud-coated : total thickness of slab, approx. 1½ in.

One of the technical difficulties so far inherent in road emulsions is to produce a quick breaking emulsion that is suited to both normal and fine aggregate. To meet this a type of road emulsion was developed which showed reasonable behaviour with a mineral aggregate of a wide range of particle size, so that light traffic could be carried by

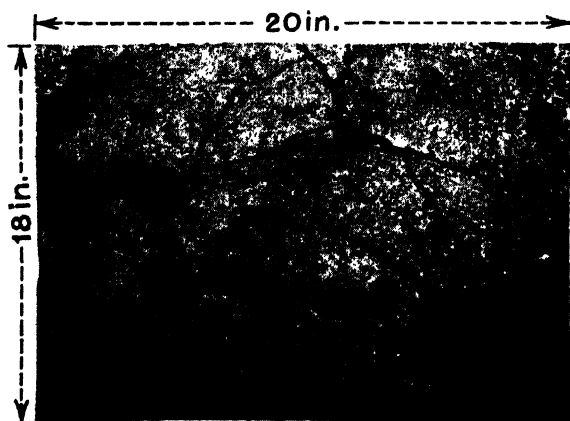


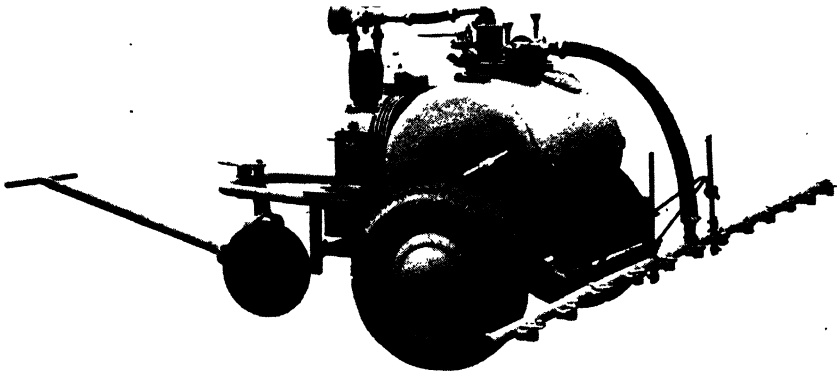
FIG. IV.13.—Cracks in Asphalt Surfacing made Traffic-worthy by means of Emulsion.
(The slab was re-broken along the old cracks for purposes of photography.)

almost any kind of local earth (that does not contain too much clay) or desert sand when consolidated with this emulsion. It can be used in mix-in-place, or for machine or hand pre-mix methods; and the final surface coat contains 3-5 per cent. bitumen. Progressive rolling during several days is necessary, so that the water that is slowly

liberated from the relatively stable emulsion may escape. A final surface dressing with a normal emulsion is desirable.

The *Pre-mix* method has been developed, and experience shows that it forms a satisfactory road-surfacing system. The suitable emulsion contains about 50 per cent. bitumen; for fine aggregate, about 55 per cent.

The mineral matter is coated with an emulsion in a suitable mixer previous to spreading it on the road. After being left undisturbed for a sufficient time for the emulsion to break, it is rolled. Such construction is suitable for 1- and 2-coat work; and for surfacing old stone setts preferably $1\frac{1}{2}$ in. thick. It is interesting that the whole mixture can be stored for a time without substantial deterioration.



By the courtesy of Emoleum, Ltd.

FIG. IV.14.—Portable Road Emulsion Sprayer.

This behaviour results from the use of increased proportion of emulsifier or of stabilizers of special properties.

The use of emulsions in road making has been highly developed in Australia, by Emoleum, Ltd. Their broom-drag methods for obtaining an even surface (for which world priority since 1931 can be claimed) involve 'multiple-coat surfacing': the emulsion is lightly applied, and liberally covered with chippings, which are alternately rolled, broom-dragged, and rolled again, before being grouted with emulsion and covered with further chippings. A second and sometimes a third coat is similarly added, to form a carpet which provides the road with an even and true-riding surface. A novel and highly efficient emulsion sprayer has been developed, one of which is illustrated in Fig. IV.14.

Repairs and emergency work are carried out with much success

by means of emulsions. The use of scarified material can be facilitated by mixing into it a small percentage of stable emulsion, either by mix-in-place methods or by passing through a suitable mixer.

Soil Stabilization can be satisfactorily effected with emulsions, especially where fluctuating proportions of water are present in a sub-grade causing changes in its volume and therefore distortion, or in its bearing power. Usually the presence of 3-7 per cent. bitumen is sufficient. The admixture is effected by hand or by a mixer of the concrete-mixer type.

Traffic.

It is difficult to define the traffic that an emulsion road can carry. The claim to be able to carry the heaviest traffic is, perhaps, extravagant: the relegation of emulsions to the class of temporary platiatives and patching materials is as exaggerated in the other direction. Given a good foundation and all other things being equal, well-made emulsion roads—grouted or pre-mix—will give good service on all but the heaviest traffic routes.

Technical Position.

These scientific and technical considerations can now be united with practical experience to examine the position that emulsions are able to take in the science and industry of road making and the advantages in its use.

1. The bituminous binder has been heated to the minimum extent during manufacture and not at all during application.

2. The road can be treated in dry or reasonably wet weather.

3. They are conveniently transported and easily and quickly applied, requiring no complicated machinery, and no heating on the site.

4. Penetration is satisfactory, even in ordinary cold weather.

5. The finished surface forms an elastic cushion, dustless and waterproof.

6. Construction and maintenance costs are low.

7. The finished surface is dry and stable, and, with suitable and sufficient grit, there should be no picking up even soon after application. Unless an excess of emulsion has been used, the surface should be permanently non-skid.

8. It was once a gibe at emulsions that only half of what is paid for is of use for road making and that it is ridiculous to pay for the transport of water; but in fact the water constitutes the vehicle that carries the binder into the desired position and depth. The emulsion is claimed to be superior to molten dressings in this respect, particularly

when the temperature of the air or of the road is low. It is obvious, for instance, that a hot dressing could not have effected the results obtained by the use of emulsion, in the case referred to on page 131. Furthermore, an emulsion dressing can usually be applied more thinly than hot dressings, which often become chilled before entering or fully penetrating the surface. Thus, actually less of the bituminous substance is put on the road, with an associated reduction in the quantity of chippings required, and the final road surface does not bleed.

There is also the important hygienic advantage to the workers as compared with hot tar, in that they are not subject to injurious spray or fumes.

Failure of emulsions may result from many causes—use of the wrong grade of bituminous material ; unstable emulsification ; faulty, excessive, or deficient stabilizer ; contaminated water ; dirty or dusty aggregate or road surface ; faulty application ; and the freezing of the emulsion, though emulsions can be made that are unaffected by frost.

Bitumen Emulsion—Rubber Latex Mixtures. Several attempts have been made to utilize the best properties of asphaltic bitumen and of rubber for road making purposes. The experiment was most interesting, but it did not succeed.

A typical example of such a mixture ³⁴⁴ consists of 90 per cent. of a 60 per cent. bitumen (40–50 pen.) emulsion and 10 per cent. (both by volume) of a 33 per cent. rubber latex, whereby the finally deposited film contained 5 per cent. rubber. The advantage claimed lay in increased resistance to atmospheric conditions and solvents, and remarkable rubber-like recovery after elongation. The properties of the material were approximately :

Water	40%
Viscosity (Saybolt Furol)	21
Size of particles, abt.	1 μ

The variation of penetration with temperature is much less than with asphaltic bitumen alone :

Temperature ° C.	Penetration.	
	Asphaltic Bitumen 40–50.	Coagulated Colastex.
15	12.5	41
20	28	44
25	48	49
30	91	58.5
35	160	155
40	Over 200	Over 230

PART V

ROAD SURFACES

BITUMINOUS ROADS

There is no more scientifically and technically difficult section of road making than this.

From the moment when the components of the surfacing are brought together, uncertainty raises its demon head aggressively. When it is considered that in the selection of materials and at every stage of preparation, transport, laying, and rolling, any single fault in quality or procedure, or change in state of the weather, may result in the failure of the surfacing, high efficiency of the operating and laboratory staffs may be inferred whenever the narrow margin between success and failure is not overstepped.

Instances are known to the Authors, where the quality of the sand has led to disaster : in one case it contained a small quantity of decayed shell which absorbed sufficient bitumen to reduce its cementing qualities below that required permanently to hold the mixture together.

The *formation* of a coherent road surface of this type depends on the particles and fragments of a mixture of suitably tough and graded broken stone, sand, and filler, being completely covered by a bituminous binding material which is more fluid when applied than it is later when set, and which, at the same time, fills the voids in the mineral aggregate.

Various graphical methods have been suggested for ascertaining the amount of bituminous material required to fill the voids of a mineral aggregate ^{94, 95, 441}, but it is very doubtful whether they can replace the proper experimental determination (see ⁴⁵²).

This doubt is partly due to the relationship having been attempted on the basis of the thickness of bitumen film required for the purpose, with insufficient attention being paid to the porosity of the aggregate, subsequent compaction, and the comminution of the particles under use.

H. M. Croeser, of South Africa, claims to have solved this problem by means of a formula which takes into consideration all these factors, to be found once and for all for each type of stone. For example, for a sample of dolomite :

$$\text{Percentage of Bitumen} = 0.01[0.15a + b + 2c + 5d + 8e + 10f]$$

where a represents percentage by wt. of aggregate passing $\frac{1}{2}$ in. and retaining $\frac{3}{8}$ in.

b represents percentage by wt. of aggregate passing $\frac{3}{8}$ in. and retaining No. 4.

c represents percentage by wt. of aggregate passing No. 4 and retaining No. 10.

d represents percentage by wt. of aggregate passing No. 10 and retaining No. 44.

e represents percentage by wt. of aggregate passing No. 44 and retaining No. 100.

f represents percentage by wt. of aggregate passing 100 (dust).

It was originally thought that every particle of the mineral aggregate, graded from the coarsest fragment of broken stone to the finest grain of the flour of the filler, contributed to minimizing the voids later to be filled by the bituminous cement (see *Voids*). In practice, it is highly unlikely that this happens. It is far more probable—considering surface activities experimentally observed in very minute particles—that the cementing material takes up the filler, forming a filler-bitumen mixture, which then behaves in the expected manner of filling the voids of the remainder of the aggregate. It is true that these voids are now filled by less bituminous material than if the filler had been absent, and to that extent the filler particles may be said to have partially filled the voids; but it has done so in league with the cementing material rather than as a constituent of the mineral aggregate. Filler contributes to the stability of the road rather in giving ‘body’ to the matrix and raising its softening point, than by behaving like the youngest brother of broken stone.

The *production* of these surfacings is achieved by mixing the components in the well-known manner, or, in some cases, by introducing the bituminous cement into the mixer as a cold hard powder, preceded by a petroleum or creosote flux oil; or by forming a water-bound surface and grouting it with a hot bituminous preparation, or by means of a cold cut-back bitumen or tar, or with emulsion; or, finally, the road-stone may be coated hot, and kept in store, and laid and rolled into position when required.

Further and lower grade but valuable methods consist in surface treatment by spraying, with or without subsequent gritting; and surface painting as a seal coat.

If there should be any absorption of the bitumen or tar by the mineral aggregate, the action will cause complications. It will be selective, not only because the lighter components will proceed further

than the heavier, but also because adsorption phenomena will cause certain substances or groups of substances to be held by the solid stone ; each activity to the contrary of the other.

This absorption can be so great as to upset the balance of an otherwise successful road mixture ; an extreme figure of 25 per cent. was obtained under experimental conditions ³⁴².

From the beginning the impossibility of using *wet aggregate* for the manufacture of the traditional form of asphalt has been disastrously emphasized oftener than a contractor likes to remember.

Great care in the drying of the mineral component has always been taken, and any fault in this has been realized with grave misgiving, often to be fully justified. The advent of emulsions focussed attention on this problem, for here was the aggregate being drenched with water (with bitumen in suspension) which, nevertheless, did not prevent good adhesion.

In addition to this, the increasing desire to use local stone led to experiments in employing gravel, the hydrophilic character of which made adhesion with bitumen precarious. Attempts were made in Hampshire to overcome this by means of a cement coating to the gravel, and before the War a commercial firm produced it.

During the War, the rapid development of aerodromes made imperatively necessary the use of large quantities of sand asphalt, and this without the occupation of time and plant for drying. In a short while the Shell Co. produced a mixture made with cold sand containing 7-10 per cent. water, which was able to carry very heavy loads. This was achieved by adding about 2 per cent. of hydrated lime and then 4-7 per cent. of a Special Road Oil at 200° F. Complete coating of the sand resulted with sufficient stability of the mixture. Sometimes the conventional mixer was employed ; sometimes a traveller-mixer picked up the sand and lime, which had been formed into a windrow, mixed it with the bitumen and laid it ready for subsequent mechanical spreading. The asphalt was consolidated to 4-5 in. Thus another revolution in surfacing has occurred ; an adaptation of this method has led to some promising trial roads being laid.

More detailed work on this same extremely important problem has been done by the Road Research Laboratory, which has been summarized as follows ⁴⁹⁹ :

- (1) Bituminous road mixtures made with cold and wet aggregates, though unlikely to supersede those made by the normal methods, should be of value where saving in transport, equipment, and fuel is important.
- (2) Satisfactory mixes can be obtained

with most aggregates by the addition of 1 to 2 per cent. of hydrated lime or Portland cement before the binder is added. (3) Larger sizes of stone are more difficult to coat than smaller sizes. (4) Limestone, some igneous rocks, and slag gave better results than a quartzite or porphyritic rock. (5) The viscosity of the binder must be varied according to the prevailing temperature and according to the type of stone. When the viscosity is less than 20 seconds at 30° C. it may be advisable to add 1 to 2 per cent. of hydrated lime or other fine filler after coating is complete. (6) Aggregate grading should conform to standard specification for dry aggregate. When the aggregate contains more than about 10 per cent. of material passing $\frac{1}{8}$ -in. mesh it is advisable to screen out the fine material and add it to the mix after coating the larger stone. (7) The binder content should usually be the same as for dry mixes, but a slightly higher content is required with a few types of stone. (8) The resistance of bitumen binder to displacement by water is considerably increased by the addition of a wetting agent. With a tar binder no wetting agent is required. (9) Bitumen cut-back with creosote coats wet aggregate much better than bitumen cut-back with kerosene. (10) The addition of a metallic salt solution to the aggregate and a soap to the binder, without hydrated lime, has not proved successful on a large scale. (11) The double-type of mixer has proved most suitable.

Very recent experimental tar surfacings have been put down in Hampshire on behalf of the Road Research Laboratory, using a liquid added to the tar. It is too soon for deductions to be drawn ⁴³⁰.

Stability.

The prime aim in designing bituminous mixtures is stability. The characteristics of the components concerned in resistance to displacement under traffic are numerous and various, but the most important may be summed up as follows :

Asphaltic Bitumen or Tar : degree of hardness and proportion ; absence of swelling.

Filler : nature, proportion, and grading.

Mineral Aggregate : nature, proportion, grading, particle, shape, and cleanliness.

Consolidation : correct weight, speed, and length of time of rolling ; temperature of surfacing.

Atmospheric Influences have a hardening effect, but knowledge is still vague.

The stability of bituminous surface mixtures depends primarily on

the interplay of the surface tensions of the stone and of the bituminous binder, and this with the capacity of the latter for wetting the former : this constitutes the phenomenon of *adhesion*.

The basis of the relationships is the behaviour of the stone towards water : it may be hydrophilic (water-loving) or hydrophobic (water-hating) in its nature, independently of its geological origin. It is the latter type to which bituminous substances adhere the better ; for instance, limestone is found to be hydrophobic and offers good adherence ; flint is hydrophilic and adhesion is usually poor.

The contribution of the liquid to adhesion is its ' polarity.' A polar substance is one containing some characteristic and active group of atoms, such as the acid group —COOH . Such substances would attach themselves to limestone (a basic substance) through these groups, while the rest of the molecules stand free " like a field of corn." There is some doubt whether true chemical reaction takes place.

At the same time the degree of surface irregularity provides a mechanical ' tooth-in-jaw ' locking which is valuable to stability ^{468, 469}.

Finally, stability depends on the proper behaviour of the components when mixed together and on good laying (see especially ¹³³). Exudation of the bitumen may be due to excess being squeezed out ; or it might be due to capillary rise of the binder when viscosity is lessened by rise of temperature ¹⁵⁰.

The break up of an asphalt surface has been suspected to occur from the insinuation of a thin mixture of dust (clay is worst) and water between the mineral aggregate and the binder, opening the way for the entry of water and subsequent damage by traffic ³³⁶.

In view of the experience of the reader and the discussions elsewhere in this book, these points need not further be elaborated here, except in the important matter of *cracks*. These may arise from excessively rapid downward variation in temperature ¹⁶², and are generally not dangerous, as a subsequent rise and the action of traffic usually seal the surface. Another cause lies in errors in the quality, proportions or mixing of materials, and faulty construction. Cracking can also be caused by the tension exerted by the drying of bovine excrement ; also by the contraction of paint for traffic lines. Failure may also be due to the cracking, breaking up, or collapse of the foundation.

It has been pointed out (in Detroit) that the asphalt mixture for passing traffic may become rutted and cracked under standing traffic, and that mixtures suitable to take this would crack under moving vehicles. To provide resistance against standing traffic the following construction is recommended to be laid next to the footpath :

Stone or Slag (passing $\frac{1}{4}$ -in., retained 10-mesh)	.	.	.	.	.	.	.	.	.	%
Sand (sheet asphalt grading)	.	.	.	.	.	.	.	.	.	60
Filler	.	.	.	.	.	.	.	.	.	25
Asphaltic Cement (60-80 pen.)	.	.	.	.	.	.	.	.	.	8
	.	.	.	.	.	.	.	.	.	6-7

This after laying is to be sealed by a mixture of the following approximate proportions :

Sand	.	.	.	.	.	.	.	.	.	.	%
Filler	.	.	.	.	.	.	.	.	.	.	80
Road Oil (SC-4A grade)	.	.	.	.	.	.	.	.	.	.	6
	.	.	.	.	.	.	.	.	.	.	5

mixed at a temperature of not over 225° F. ⁵⁴².

It may not be out of place to refer here to the attitude of the *motorist*, as he can act destructively on a new road surface. His resentful feelings against the local engineer when bituminized sand or chippings fly up and stick to his car's glossy surface and leave an ugly mark, are equalled by those of the engineer who considers that the motorist should drive more carefully over a newly blinded or chipping-treated road surface in order that this material shall not be flung about and rendered useless. Some inconvenience to the motorist is inevitable, and reasonable care must be exercised by him during the time, often very short, that the dressing takes to settle down. By being unselfish about speed and selfish as regards the appearance of his car, the motorist can help the road maker to help him.

Voids.

The significance of this word is twofold : it covers (*a*) the voids in mineral aggregate that have to be minimized by suitable grading and filled with bituminous binder, and (*b*) the small air pockets in the surfacing due to air entrapped during the distribution and spreading of the mixture before consolidation. The former are dealt with in connection with 'Mineral Aggregate' ; and the latter must be considered now, as they are a valuable indication to the condition of the road.

Their proportion (ascertained by comparison of observed and calculated densities of the mixture) is a measure of the degree of the consolidation of the surface : too high a percentage (say, 16 per cent.) indicates insufficient compaction and likelihood of early disintegration ; too low a figure (in most cases about 2 per cent.) indicates an approach to complete solidity and a diminished capacity to absorb shock, and an increased possibility of fracture. A good figure, early in the life of a road, is 9 per cent. in sand carpet, and 5 per cent. in chipping carpet and binder. Such are the conditions for orthodox carpets, but the newer carpets have modified this.

Although these possibilities are truly indicated, the great complexity of the influences simultaneously controlling the life of a road must be remembered, so that such simple prognostications as the above are not certain by themselves ; but they form an important matter to be kept in view. (See also *Rock Asphalt*.)

ASPHALT SURFACING

The first asphalt pavement was laid in the City of London in Threadneedle Street, in May 1869. By the end of 1873, the following 'asphalte carriageway pavements' had been laid in the City ¹³⁵ :

Pavement.	Length, yards.	Superficial Area, yards.
Val de Travers (Compressed) . . .	4,185	34,876
„ (Mastic)	69	232
Limmer („)	1,446	8,477
Barnett's („)	1,705	16,544
Société Française (Compressed) . .	39	327
Montrotier („)	40	346
Total	7,484	60,802

Asphalt is used for road making in the following forms :

Rolled Asphalt (Hot Process), a manufactured mixture, made, laid, and rolled hot or warm ;

Rolled Asphalt (Cold Process).

Rock Asphalt, spread hot in powder form and consolidated by means of hand rammers, and ironed ;

Rock Asphalt Non-skid Surfacing ;

Mastic Asphalt, spread hot by hand floats ;

Asphalt Slabs or Tiles, made of highly compressed asphalt rock, or modified sand carpet mixture, and laid by hand.

These processes have been well described with valuable comments ⁸⁸.

Asphalt Macadam, Penetration method.

Bitumastic Macadam is a term, not widely used, for aggregate mixed with cut-back bitumen, or with a tar-bitumen mixture.

Up to 1928 there was no recognized standard or quality of the components of these mixtures or their proportions. Such untrammelled freedom of manufacture, with no other basis than the judgment of experience, led to the laying of continuously 'improved' (really experimental) mixtures and the observation of their behaviour over a number of years. The accumulation of such knowledge, together with laboratory work, was such that, after long discussion, a set of

British Standard Specifications were issued at the end of 1928. These regularized the whole situation, and upon them the Ministry of Transport bases its relations with asphalt construction.

It was found, after four years, that good roads could be made with mixtures outside the proportions and qualities specified⁸⁸, and also that loopholes existed that made tendering uncertain. In addition to this, the less damaging effect of pneumatic-tyred vehicles, together with economic conditions, created a demand for asphalt roads of a type less expensive than the best, for roads of medium and light traffic, whilst still preserving strict scientific justification. Thus the situation became changed, and the 1928 Specifications were revised in 1933; they were undergoing reconsideration in 1946 and onwards.

The general *trend* of asphalt road construction is thus seen to be in the direction of two specialized types: one for the highest class of roads carrying the heaviest traffic, and the other for less punishing weights and smaller quantities of vehicles. The division between these two differentiated types is tending to be blurred by the production of fine-grained thin carpets which appear to be standing up to heavy traffic—'bus, lorry, and commercial vans—with remarkable stability. In addition, the direction in manufacturing is towards an ever-closer control of conditions, and a still closer supervision at the laying end.

According to earlier ideas, the ideal bituminous road consisted of a minimum-void mineral aggregate filled, or slightly overfilled, with a bituminous binder to ensure a watertight and mechanically uninjurable surface. Latterly, a search for a more efficient, economical, and skid-free surfacing has led to a lowering of the compaction of the mineral aggregate so as to preserve resilience and to avoid risk of breaking up through shock when laid on a rigid base; and also to a diminution in the proportion of binding material, whilst retaining the necessary waterproof quality. This improvement became possible through a greater choice in the grades of the bituminous materials.

In *hot-rolled asphalt* there has been a tendency towards the use of softer bitumen and lower temperatures of manufacture, a slight reduction in the proportion of the asphaltic cement used, and a careful adjustment of the percentage of mineral aggregate.

Also, two-coat work with chipping carpet (fine-grade aggregate) has been giving way, more and more, to a single-coat construction containing a high percentage of large stone—40–70 per cent. retained 8-mesh sieve (B.S.S.). Cut-back bitumen increased for second-class types of mixtures.

Compressed asphalt procedure shows little tendency to change, except for the use of pre-coated chippings, rammed in to form a rough

surface. Two-coat hot-rolled work replaces wood blocks in preference to the conventional compressed asphalt, as the latter is not suitable for such thicknesses.

When the available depth is sufficient for a superimposed layer of new concrete at least 3 in. in thickness (upon the existing concrete) and 2 in. of compressed asphalt, this form of construction is often adopted for heavy traffic. In *mastic* work, the chief development has been towards mixing in a central depot, and heating and stirring during transport. There is, however, a diminishing tendency in its use, mainly due to cost. It is in demand mainly for repairs and footways. *Tiles*, made from pure compressed rock asphalt, or *Mastic Slabs* from a mixture containing rock asphalt, have been favoured for use in localities where extra heavy service is required, as at 'bus stops.

Hot Rolled Asphalt.

This heading would have been synonymous with the term 'hot mix', had it not become endowed with wider significance, which covers the following methods :

Hot-Mix Asphalt is the long-established process of this class, and need not be described in detail. The significant details of manufacture are established in the British Standard Specification (594 : 1945).

Clinker Asphalt. The use of municipal destructor clinker for road construction—at first mainly for foundations and concrete flags—began in Hornsey (London), in 1894, by its inventor, E. J. Lovegrove ; in particular, he stressed the desirability of blending various grades of clinker.

In Fulham, preliminary experiments were carried out about 1908 by Francis Wood ; and success was achieved when at last a well-balanced mixture was found, with the co-operation of the Trinidad Lake Asphalt Paving Co., Ltd. (as it was then). This was the more remarkable as the traffic in those days was iron-tired. In 1911, experimental sections of single coat, 3–2½ in. thick, were laid in conjunction with the Road Board, to a specification of :

	%
Asphaltic Cement (fluxed Trinidad Lake Asphalt. pen. 170 at 25° C.)	10
Chalk	4.6
Sand	27.7
Clinker 1 in. down	57.7
	<hr/>
	100.0

Repairs were necessary in 1914, but the usefulness of clinker as an aggregate was shown to the satisfaction of the officials.

The development of motor traffic hastened that of clinker asphalt in 1913, and soon it became possible to carry omnibus traffic up Muswell Hill, with a gradient of 1 in 8.5.

This new and successful asphalt was laid 4 in. thick and rolled in two layers, and consisted of a mixture with Trinidad asphalt and Mexican E grade bitumen. The early gradings are shown in Fig. V.1, where it is seen that the fine material used for flat and medium gradients is roughly the converse of the coarser material required for sharp bends and gradients. Incidentally, this is a vivid way of showing approximate gradings.

Mr. A. F. Holden continued the Fulham experiments, screening the crusher run material and remixing to secure varied gradings and gradually reducing the maximum size of clinker aggregate to as low

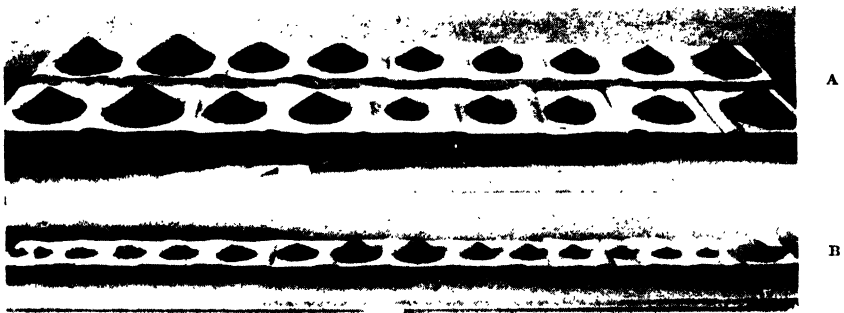


FIG. V.1.—Grading of Clinker for Clinker Asphalt.

A. Two typical samples of fine aggregate : from right to left :

	Passing 200 mesh	100	80	50	40	30	20	10	1/2-in.	%
										20
										10
										8
										7
										7
										8
										10
										20
										10
										100

B. Typical grading of coarse aggregate, from passing 1/2-in. mesh to 200 mesh : it is practically the reverse of the grading of A.

as 1/2 in., as large sizes were found to crush under traffic. Later, in 1929, 'cubical' granite was embedded in the surface, perhaps for the first time, to form a non-skid surface.

During the Second World War, exceptionally thick asphalt—up to 10 in.—was successfully used where speed of construction was vital and finished levels had to be considerably above existing foundations ; skill in rolling—first with a 3-ton and then with a 12-ton roller—at

the proper temperature was very important. These thick layers, when later cut out, have been found completely homogeneous, the separate layers having amalgamated.

The vesicular nature and the low specific gravity of the clinker led to the requirement of apparently high percentages of bitumen, when these were calculated, as is usual, by weight : base coat, 13 per cent., wearing coat, 16.5 per cent., as compared with normal asphalt of about 9.5 per cent. However, it has been found possible to lay roads for carrying especially heavy traffic consisting of a mixed clinker-gravel aggregate with 6.5 per cent. soluble bitumen in Trinidad Lake Asphalt.

In judging the value-for-cost of clinker asphalt, attention should be given to the economies affected by the use of a waste material, which may be more ' local ' than the supplies of stone and filler.

A characteristic clinker asphalt surfacing of to-day consists of :

Soluble Bitumen	.	.	.	.	.	.	%
Passing 200	.	.	.	.	.	.	16.7
36	.	.	.	.	.	.	33.6
25	.	.	.	.	.	.	10.2
18	.	.	.	.	.	.	5.3
8	.	.	.	.	.	.	4.0
$\frac{1}{8}$ in.	.	.	.	.	.	.	6.5
$\frac{3}{16}$ in.	.	.	.	.	.	.	8.4
$\frac{1}{4}$ in.	.	.	.	.	.	.	5.0
$\frac{3}{8}$ in.	.	.	.	.	.	.	4.3
$\frac{1}{2}$ in.	.	.	.	.	.	.	5.0
	.	.	.	.	.	.	1.0

							100.0

Electromagnetic separation from the crushed clinker of iron objects, such as nails, bolts, etc., is desirable before mixing with bitumen, non-magnetic material can be separated by hand during laying.

Open-textured Carpets have been made the study of a *Wartime Road Note*, No. 3 (1941, reissued with minor alterations as *Road Research Bulletin*, No. 5, 1946), by the Road Research Laboratory. Much experience had been gained on thin surfacings of $\frac{3}{4}$ in. to $1\frac{1}{4}$ in. thick and this, together with several years of trials, has led to the ' Recommendation ' on the subject.

Coarse aggregate not bigger than $\frac{1}{2}$ in., sand passing $\frac{1}{2}$ -in. sieve, and filler of which 85 per cent. passes a 200-mesh sieve, are all mixed with 4-5 per cent. binder, which may consist of cut-back bitumen of 180-220 pen., asphaltic bitumen, or fluxed lake asphalt. With cut-back bitumen, aggregate at 55-70° C. is mixed with binder at 95-100° C. ; with asphaltic bitumen, aggregate at 80-100° C. is mixed

with binder at 125–140° C. Gravel is the most difficult aggregate with which to get adequate adhesion, and success is doubtful if the moisture present is much above 1 per cent.

A matter of some importance is the *loss of heat* between the mixing and the finished hot-mix surfacing. This depends greatly on the temperature of mixing, the time of day and period of the year, length of haul, and the meteorological conditions. The following figures are given as being the average between fairly wide limits, the irregularities observed being caused by such slight variations in working, shaking in the wagon, etc., as are normal in ordinary practice: they are, however, nothing more than indications.

Short Lead.

	Loss of Heat. ° C.
On mixing sand with cold filler (cement) (calculated)	19
On adding bitumen	0
After 3 minutes' mixing	11
	30
During transit	0
„ standing	0
„ dumping	0
„ raking and waiting for roller	80
	110° C.

Long Lead.

After 3 minutes' mixing of bitumen, sand, and filler	25°, 17°
After 2 2½ hours' transit when the mixing temperature was 165°. Depth in load	2 in. 32°
„ „	4 in. 2°
„ „	8 in. (and over) 0°
After 2-2½ hours' transit when the mixing temperature was 220°. Depth in load	2 in. 70°
„ „	4 in. 39°
„ „	8 in. (and over) 12°
Standing in wagon, ½ hour	8°
1 „	12°
2 hours	22°
2½ „	22°
4½ „	33°
During raking	70°
Awaiting roller (4 mins.)	11°

Penetration Method.

The aggregate is consolidated by asphaltic bitumen that has been introduced subsequent to its formation, and this may be done by one or other of two processes.

The *hot process* is governed by the B.S.S. 347 : 1928, where the cementing material is applied at a temperature of 275–405° F., and blinded with $\frac{3}{4}$ -in. chippings and rolled.

The *cold process*, which may be employed for full or semi-grouting, entails the use of a bituminous emulsion, according to the B.S.S. 433 : 1931. A one- or two-coat construction is required according as the final thickness is to be 3 in., or over.

Pre-coated Asphalt (hot or cold).

Mineral aggregate, pre-coated with asphaltic bitumen, is increasingly used. The dried stone is mixed at 90° F. with the bitumen at 200° F. (less, if the mixture is to be stored), in the proportion of 7 gal./ton with coarse aggregate and 10 gal./ton with fine.

The coarse stone grading used is

1½ in.	.	.	.	.	.	.	.	.	60 per cent.
¾–1 in.	.	.	.	.	.	.	.	.	40 „ „

with 3 per cent. of material all passing $\frac{1}{8}$ -in. mesh sieve. For top coat, $\frac{1}{4}$ – $\frac{3}{4}$ in. stone, with 5 per cent. of material all passing $\frac{1}{8}$ -in. mesh sieve.

Compressed Rock Asphalt.

There is little to say about this material, as there is no important departure from normal practice, which is laid down in the B.S.S. 348 : 1945.

What was previously a slippery form of surfacing is no longer so, as pre-coated chippings correct this (Fig. V.2), and can be expected to remain in place if rammed in at the proper temperature (Fig. V.3).

With regard to the resilience, and absorption of traffic shock and vibration : these are bound up in the voids—air spaces in the mixture ; and it is interesting to note that this mode of construction is such that this desirable property is produced to an important degree. When the voids were determined at the top and the bottom of a compressed asphalt carpet the following were found :

Top	.	.	.	.	.	1.8	3.5	5.2
Bottom	.	.	.	.	.	11.8	12.9	16.8

which show clearly how the surface has become hardened, and the lower portion preserves its source of resilience.

Rock Asphalt—Non-skid Surfacing was first used in 1936, and large areas have been laid. It can be used on any type of asphalt surface in the following manner :

The surface to be covered is swept clean and a spirit bitumen paint is applied at about 30 sq. yd. to the gallon. On the painted surface is spread cold asphalt powder to a thickness of $\frac{1}{2}$ in. On this

loose powder is spread asphalt macadam, composed of 2 parts 1-in. basalt and 1 part $\frac{3}{4}$ -in. light-coloured coarse-grained granite, which have previously been coated with bitumen ^{547, 616}, at 35–40 sq. yd. per ton. After about 50 sq. yd. have been laid, the mixture is rolled



FIG. V.2.—2-in. Compressed Rock Asphalt being finished with Pre-coated Chippings.
(Note board in the channel to allow subsequent flow of water to be unhindered.)

with a roller of not less than 8 tons. Finally, asphalt powder is lightly brushed into the interstices, after which the area can immediately be opened to traffic. This type of construction can be looked upon as being the most important advance in asphalt road technique of recent years, and so great is the confidence in it that 10 years' unconditional guarantee is given by the contractor.

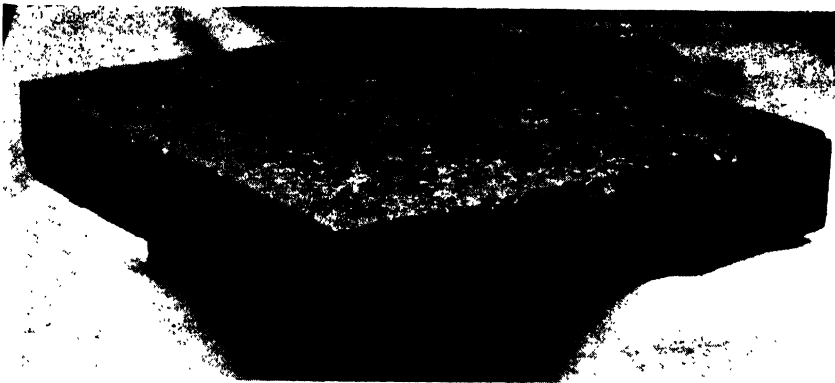
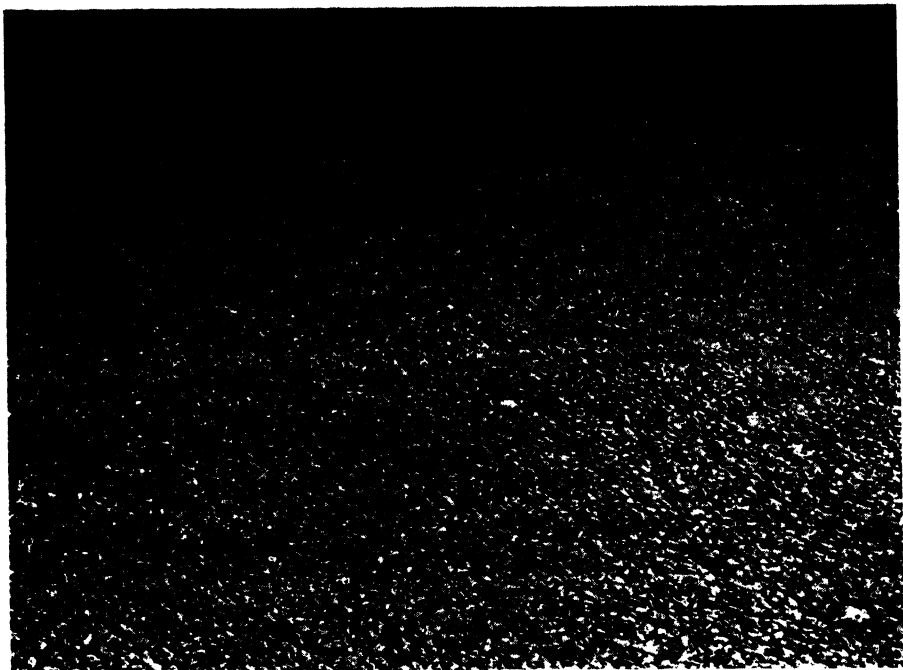


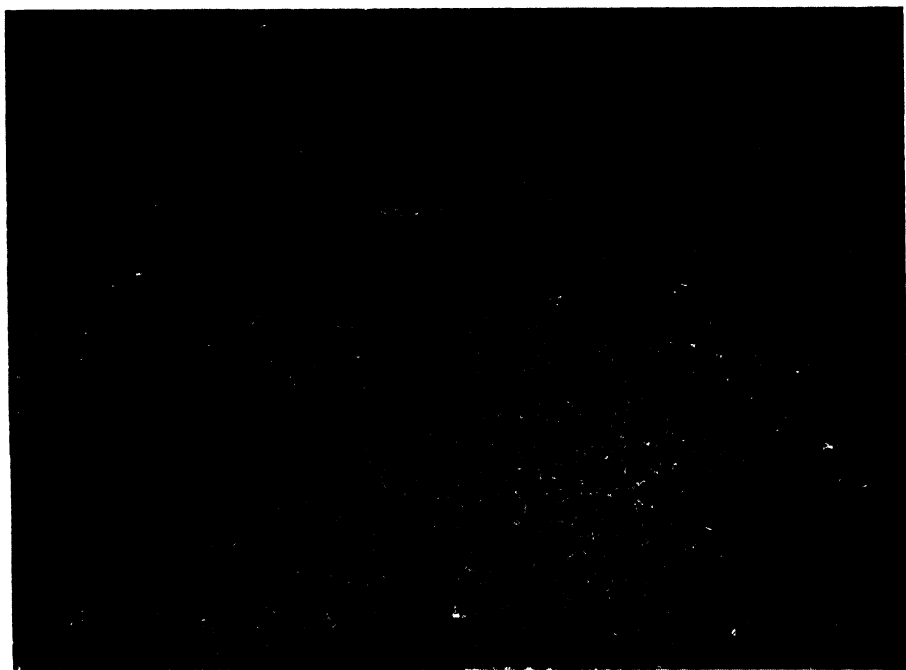
FIG. V.3.—Compressed Rock Asphalt Surfacing, showing Chippings remaining in place after three years' service under heavy traffic.

A somewhat similar mixture that has been successfully used consists broadly of 90 per cent. granite (or similar aggregate) graded $\frac{3}{4}$ in. to $\frac{1}{4}$ in., 5 per cent. cut-back bitumen, and 5 per cent. fines, mostly passing a 200-mesh sieve, into which some natural rock powder has been mixed ; this gives a very effective stabilizing action.



By the courtesy of the Asphalt Roads Association, Ltd.

FIG. V.4.—Non-Skid Asphalt Surface laid in 1936.



By the courtesy of the Asphalt Roads Association, Ltd.

An impressive example of rock asphalt surfacing has been laid 2 in. thick with large stone aggregate in accordance with the specification of 1935. In appearance it is not rock asphalt containing stone, but large stone cemented together with the minimum of rock asphalt. In Charles II Street (London) some was laid in 1939, and in 1946, after carrying mainly taxi traffic, it seems to be very little changed, and to retain a nearly perfect non-skid surface.

Other examples of non-skid asphalt surfaces are shown in Figs. V.4 and V.5.

Mastic Asphalt.

Mastic asphalt consists of finely ground rock asphalt or limestone or both, mixed with fluxed lake asphalt or with refinery bitumen of relatively high penetration, in excess of that required to fill the voids of the mineral aggregate. It is this latter condition that enables the mixture to flow under a hand float. The significant details are laid down in the B.S.S. 596:1945 which is in two parts, controlling the use of natural rock asphalt aggregate, and of limestone aggregate.

It has long been the practice to prepare the mastic cake by heating and stirring the mixture for hours in a cooker, in order, it is said, to effect perfect blending and equalization of quality; and it is again heated and stirred with added chippings before it is laid on the road. It is a matter of certainty that prolonged heating hardens the bitumen, and it is doubtful whether it is really necessary.

This hardening may be the cause of such stiffness under the float that the men sometimes find the mixture difficult to manipulate, which has led 'Old Bill' to add a few candles to diminish the viscosity (though he does not express it in this way). The contractors who consider that paraffin wax is undesirable in a mastic, and pay more for a bitumen that is relatively free from it, are justified in taking strong measures when it is deliberately added at the last stage.

The chief characteristic of a mastic carpet is its voidlessness. The mineral matter is slightly over-filled with bitumen, and the act of floating works out the bubbles of air entrapped during the preliminary mixing of the materials. It is, therefore, denser than a rolled hot mixture. There is a tendency towards the manufacture of harder grades.

Generally, the ills of mastic are those of other asphalts with the addition of one, particular to it alone—the formation of *blisters*. These may sometimes be of such a nature that they are strong enough to support a man.

Much work has been done on this,⁴¹¹ mainly in Germany, and the consensus of opinion coincides with the following statement :

“ The asphalt was found to be uniform in composition and to show no peculiarity at the point of actual blistering. The only fault detectable in any of the material was that there was evidence of small ‘ blows ’ having been produced, and not pricked at the time of laying. This led to the formation of a theory that these ‘ blows ’ lie dormant until such time as the asphalt comes under the influence of heat from solar radiation. This softens the asphalt, expands the air in the ‘ blow ’ beneath, and the asphalt is pushed up into a very small blister. At night the temperature falls, the asphalt hardens, and the air contracts. The asphalt does not, however, resume its original shape owing to its increased rigidity. In consequence there is produced a sub-normal pressure in the blister, and to compensate for this, air and/or moisture is drawn from the concrete. When the sun again shines strongly further softening and expansion takes place, and the blister increases in size. Once started, this process may go on indefinitely. . . .

Contrary to the generally accepted idea of high pressure, blisters can be produced at 35° C. with a pressure as low as that produced by a 2-ft. head of water.

Penetration obviously affects the final consistency of the asphalt, and the softer the material the more liable it is to deformation . . . a hardness number of 20 to 25 at 25° C. should be regarded as a maximum figure for footway materials if blistering is to be avoided . . . the higher the viscosity of the asphaltic cement, the less likelihood of obtaining partial and irregular adhesion with the concrete which is definitely one cause of blistering. . . . The opinion advanced by the Building Research Station that complete lack of adhesion between the asphalt and the concrete is necessary to prevent blistering has always had our support, and a cure can be found to this defect by employing a suitable membrane of paper between the asphalt and the concrete. Alternatively, covering the surface of the concrete with a thin sprinkling of Rock Asphalt or a suitable mineral aggregate will have the desired effect. In fact, any means of preventing adhesion between the asphalt and the concrete will suffice, provided that it is evenly and judiciously applied ” ⁴²¹.

This seems to be convincing and to dispose of the suggestion that blisters result from gas being generated within the mastic,³⁶⁰ but it has been pointed out that blisters have occurred in asphalt coatings on steel, and also that no blisters have occurred on a foundation known

to be wet. They cannot result from the presence of oil used for lubricating the mastic buckets, as the boiling-point of the oil is too high ; nor from a leakage of gas, as the pressure is not great enough.

Cracking of the bitumen, due to the sun's heat in the presence of mineral matter that especially aids such changes (catalysts), has been suggested ; and the presence of tar compounds has been blamed with the minimum of reason. In addition, the oxidation of sulphuretted hydrogen in the mastic to sulphuric acid (the presence of acid has been proved) and subsequent reaction with the limestone in the mixture has been suggested as a cause ; as well as the presence of bicarbonate in the limestone employed. (See ^{128, 173-7.})

And further it has been shown that the blisters on a footpath (running east and west) contain only air and water vapour ⁴⁶¹.

COLD ASPHALT

(See also ^{5.})

The development of this type of surfacing aims at a process that is simpler, quicker, and cheaper than the traditional hot mixes. Several definite principles underlie their technique, but all depend on the use of small-grained aggregate and a low percentage of bitumen, laid cold even if sometimes mixed warm or hot.

The first experiments were those on which the patent of Farrington of Paris was based in 1879. Since then, cold asphalt has become so highly developed that mixed traffic, including many omnibuses and lorries, can be carried on a thickness of only $\frac{1}{4}$ in.

The first modern cold asphalt was that of Dr. Amies of America, introduced there in 1909 and into England in 1925—just at the time when other such processes were being made public.

This type of surfacing is controlled by B.S. 510 : 1933 for Single-Coat cold process asphalt, and by 511 : 1933 for Two-Coat construction. It is noteworthy that the voids in thin fine-grained carpets are usually about 8 per cent., and seldom reach as low as 4 per cent.

The advantages that are claimed for cold asphalt are ⁶ : its laying is mainly independent of the weather ; it does not polish or track under traffic ; it has a low temperature coefficient ; it can be laid a month or more after delivery ; it affords the greatest simplicity for repairs ; it will carry traffic immediately after laying.

Bitucrete, see under *Concrete*, pages 217, 221.

The following have been chosen for description as being typical of their class :

Amiesite was the first of the cold asphalts, and depends on the flux-in-place principle. It is a two-coat surfacing of a combined

thickness of 2 in. ; but can be used as a single top course of 1-1½ in. for country roads.

A specification is :

	%
Asphaltic Bitumen	5-6
Filler	3-5
Sand	10-12
Chippings, ½-¾ in.	77-82

Kerosene is used as the volatile flux, and the asphaltic bitumen (80-100 pen.) is added at 240-250° F.

Carpave was introduced into this country in 1925. It also depends on the use of a slowly volatile mineral oil and asphaltic bitumen added successively in an ordinary mixing-plant, whereby the oil acts first as a primer and then as a cut-back-in-place softener.

The aggregate in the mixer is at about 100° F. and the 5-6 per cent. bitumen (65-100 pen.) at 240° F. ; grit and filler are added last.

The mixture is laid cold in one coat, from ¾ to 2 in. thick, or in two coats, from 2½ to 3 in. thick, and consolidated.

The proportions of the mixture are unusual :

	Consolidated Thickness.		
	1 in.	2 in.	3 in.
Coarse Aggregate	Passing ¾ in. Retained ½ in. 85-90%	Passing 1½ in. Retained ¾ in. 85-90%	Passing 2½ in. Retained 1½ in. 80-90%
Fine Aggregate, all passing ½ in.	0-15	0-15	0-20
Filler, 75% passing 200 mesh sieve, all passing 80 mesh sieve	0.5-1	0.5-1	0.5-6
Bitumen, % total wt. of asphalt	5-7	4.5-6.6	4.5-6

Voids slowly diminish from about 15-20 per cent. to about 8 per cent.

These figures have later been modified for use in thin carpets (see table, p. 155).

The penetration of the bitumen is between 83-58, and the flux oil, of 0.800-0.815 sp. gr., boils between 150-300° C. approximately.

Colprovia is a Colas product, and is based on flux-in-place principles. The dried aggregate is coated with a film of flux oil (warmed in winter, though laying in winter is not recommended), and a hard powdered bitumen is then added. The qualities and properties of the two bituminous ingredients control the resulting physical nature of the material according to the purpose required and the distance of transport.

Surface.	Grading.	Laid.	Consolidated to
<i>Carpeting :</i>			
Single Coat A . . .	$\frac{3}{4}$ in. or $\frac{5}{8}$ in. to $\frac{1}{2}$ in.	$1\frac{1}{4}$ in.	$\frac{3}{4}$ in.
" " B . . .	$\frac{1}{2}$ in. to dust	1 in.	$\frac{1}{2}$ in.
<i>Resurfacing :</i>			
Single Coat . . .	$1\frac{1}{4}$ in. to $\frac{1}{4}$ in.	Slightly over 2	$1\frac{1}{2}$ in.
<i>New Construction :</i>			
Private Roads . . .	} as above		
Unclass. Roads . . .			
Single Coat . . .			
<i>Main Roads</i>			
Single Coat . . .			2 in.
Two Coat . . .			2 in., $2\frac{1}{2}$ in or 3 in., according to traffic
<i>Thin Carpets</i>			
Playgrounds . . .	} $\frac{1}{2}$ in. to dust	As Single Coat B	
Footpaths . . .			
etc.			

The surfacing is laid $\frac{1}{2}$ –2 in. in thickness, and below it a tack coat of bituminous emulsion should be given. Immediately after initial rolling, with a 10–12 ton roller, the road can be opened to traffic ; and owing to its character a surface dressing is not required.

Colprovia can also be employed for surfacing or profiling other types of surface (quarry fines being used) to a thickness of $\frac{1}{4}$ – $1\frac{1}{4}$ in.

The material can be kept unconsolidated for long periods without undesirable change.

Dammann Asphalt. The mineral aggregate consists of suitable blast-furnace slag or hard non-absorbent stone of $\frac{1}{8}$ – $\frac{1}{20}$ in., very thoroughly mixed at about 180° F. with about 5 per cent. 180–200 penetration asphaltic bitumen, after fluxing. Tar was originally used, but was not so satisfactory. The mixture is laid cold, and after the rolling and effect of traffic, becomes compressed into a tough mass. To-day, tar is regaining its position.

It is claimed to follow the 'give' of foundations without cracking, primarily through the interlocking of the fine aggregate.

It is used as a carpet from $\frac{1}{4}$ to $1\frac{1}{2}$ in. in thickness and for repairs, without subsequent surface dressing. A treatment with bituminous emulsion is required to ensure a proper bond between the foundation and the surfacing. Appreciation has been expressed by both the

motorist and the horseman ³²⁶ of its fine-grained non-skid and self-healing surface. (For underlying principles, see ⁴²⁶.)

A development of the Dammann principle is seen in the *Eesilade* construction, providing a practically voidless and non-skid surface.

This consists in recognizing the difference in behaviour of bitumen with the relatively coarse and fine mineral aggregate. The coarse— $\frac{3}{8}$ to $\frac{1}{4}$ in.—and the remainder are separately coated at 200° F. with a special bitumen, consisting of a 65-pen. material fluxed with anthracene oil to give a Ubbelohde drop point of 33–34° C. These two mixtures are then combined in the desired proportions, laid, and consolidated to $\frac{1}{2}$ in. up to 1 $\frac{1}{2}$ in. The amount of bitumen varies between 4 and 5 per cent., according to the grading.

Resmat has the peculiarity that the mineral aggregate leaves the mixer insufficiently coated with bitumen to a carefully controlled degree. It can be produced with a rough-surfaced finish to carry fast and heavy traffic, or with a sand-paper finish for use in estate roads, footpaths, cycle tracks, and the like ; it is also suitable for repairing. It is protected by the British Patent 430,979 of 1935, for *Improvement in or relating to Road Surfacing and like Materials*.

The mineral aggregate ($\frac{1}{8}$ in. to dust), which may be of slag or stone (preferably limestone) is divided into two parts by a 20-mesh sieve. The coarser portion is heated to about 150° F. and is then treated with a small quantity of asphaltic or creosote oil. About 6 per cent. of heated bitumen of 350–400 pen. is mixed with it, and then about an equal quantity of the finer aggregate is added, cold and uncoated. The result of further mixing is a fully coated coarse aggregate in contact with finer partially coated aggregate. The mixture thereby remains for long periods free from the formation of troublesome lumps of material, but consolidates perfectly under pressure.

When laying, a tack coat of bitumen or tar—heated or in the form of emulsion—is desirable. The mixture is rolled till no further consolidation is observed ; for roadways, 2 $\frac{1}{2}$ –4 tons for preliminary rolling and 8–10 tons after precoated chippings have been spread.

These light carpets are becoming increasingly established in the favour of road makers. They differ markedly from classical asphalt ; they are relatively cheap and the best of them take surprisingly heavy traffic very well.

They are all designed on the same general principle. Stability depends on small-grained mineral aggregate, carefully graded to give the maximum 'lock' between the grains, with just enough bitumen or tar (Type B) to coat them. After rolling, such a mixture gives the minimum of voids and a non-skid 'sand-paper' surface, which changes little because there is no excess of binder to be squeezed up. (See also ⁵¹⁰.)

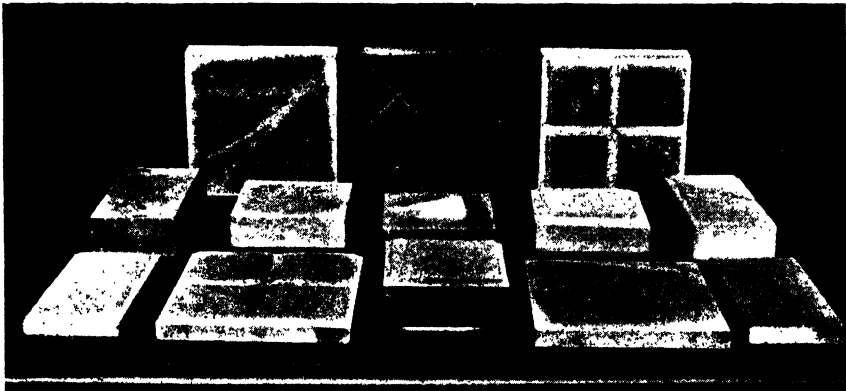
It is invidious to select for comment examples from the several good materials available, but one or two must be mentioned as being typical of this class of material.

Asphalt Tiles, Slabs, Blocks.

Asphalt tiles are controlled by B.S. 1324 : 1946 for those composed of natural rock asphalt ; and by 1325 : 1946 for synthetic asphalt. The dimensions standardized are :

	Area, in inches.	Thickness, in inches.
Natural Rock Asphalt.	8×8 ; 8×4 ; 8×5	$\frac{5}{8}$; $\frac{7}{8}$; $1\frac{1}{2}$
Synthetic Asphalt	$9 \times 4\frac{1}{2}$	$\frac{3}{4}$; 1 ; $1\frac{1}{2}$; 2 ; $2\frac{1}{2}$

In manufacture, the rock asphalt tiles are compressed at 4 tons/sq. in. ; and the synthetic asphalt tiles at 200 lb./sq. in. (Fig. V.6). Another form is of a wearing surface mixture containing rock asphalt,



By the courtesy of Messrs. Highways Construction, Ltd.

FIG. V.6.—Types of Compressed Asphalt Tiles.

compressed at 200 lb./sq. in., and are $9 \times 4\frac{1}{2} \times 1\frac{1}{4}$ – $2\frac{1}{4}$ in. in size. They are laid by hand on concrete which should be not less than 6 in. thick for heavy traffic, of rough surface, covered whilst 'green' with $\frac{1}{2}$ – $\frac{3}{4}$ in. sand-cement screeding, on which the blocks are laid whilst it is still wet, placed direct on 'green' concrete. A fine cement grouting is finally brushed over the surface. Under normal conditions about 75 sq. yd. can be laid per day by one man.

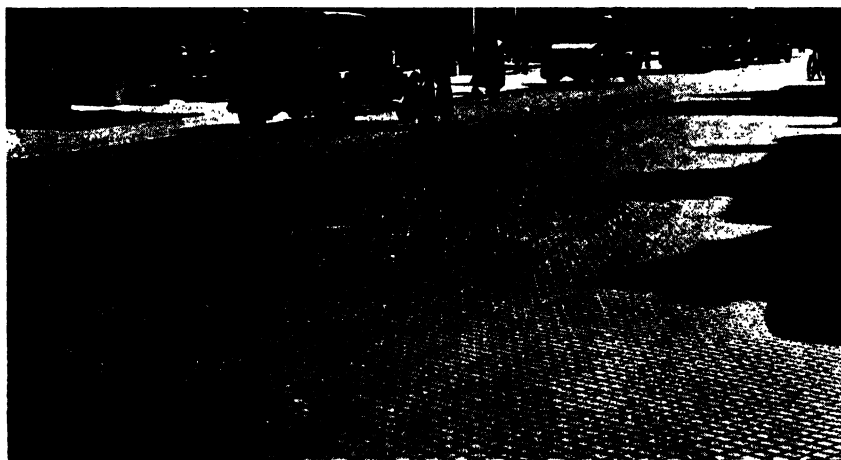
The tiles are either smooth, or more generally are provided with grooves to give a grip. They are most suitably employed for positions

of specially heavy traffic, as they carry standing, and starting and stopping vehicles well without tracking; and are stable between extremes of temperature when they contain a minimum of bitumen.

The general appearance of the paving is seen in Fig. V.7.

The general trend of road requirements has led increasingly to rough non-skid surfaces, so that asphalt tiles even when grooved have become neglected. It remains to be seen whether they regain popularity, when post-war skill in manufacture is regained.

Asphalt blocks have been made in America, consisting of a fine asphaltic concrete bound together with 6·5–10 per cent. of asphaltic



By the courtesy of Messrs. Highways Construction, Ltd.

FIG. V.7.—Asphalt Tile Paving.

bitumen of 20–50 pen. at 20° C.¹⁵². A German form has been made with heated rock asphalt, and the finished paving has certain practical advantages in easy replacement and re-use ²⁰⁴.

Coloured Asphalt, produced by the addition of colouring matter to 'albino' bitumen, is seldom if ever used for roads. Colour is added to certain commercial bitumens, which vary remarkably in the depth of their naturally dark colour; and the final effect can be enhanced by the use of coloured chippings. It is used mainly as an aid in traffic segregation and for traffic signs; also for local embellishment.

Coloured asphalt can be produced from mastic, rolled and rock asphalt. The last two mixtures are most suitable for road purposes, and of these rolled asphalt is more usually laid, though rock asphalt has been proved to be quite suitable. Red is the only colour that

is commercially suitable; it can be used in such mixtures as the following:

	2-in. Single Coat. %	Light Traffic Roads. 1 in. %	Footpath. %
Asphaltic Cement	9.0	10.0	10.5
Filler (including Pigment)	8.0	10.0	5.5
Quarry Sand	18.0	20.0	84.0
Stone	65.0 ($\frac{3}{4}$ in.)	60.0 ($\frac{3}{8}$ in.)	—
	100.0	100.0	100.0

The mixing is carried out at 250° F. with the filler and pigment added last so as to minimize the effect of the heat.

Traffic-sign mixtures are of the mastic type, a standard yellow colour being used according to B.S. 381 : 1930 (Addendum 6245 : 1932). (For *Coloured Roads*, see ⁵⁴³.)

In the memories of certain economically minded individuals there may lie the recollections of the incorporation of still serviceable asphalt surfacing, taken from the road, into new material.

During the war such practices have been recognized as a reputable part of the general salvage campaign. Desperate efforts were made in France and Germany ³⁶⁴ to use tar as an admixture in surfacings, whilst in this country old asphalt has been successfully regenerated by the adjustment of bitumen or aggregate to the broken-up and heated material under specially careful laboratory control ³¹⁰; even so considerable risk may be involved.

TAR SURFACING

The Tar Road situation is dominated by two powerful forces—the desire of the tar industry to expand in normal trade competition with bitumen; and the ever insistent national campaign to employ to the full the resources of the country. The coal industry is one of our staple industries; and its importance to the national prosperity, as measured by money paid to the owners and to the employees, and its relations with other national industries, is fundamental. In other words, the improvement of an improvable material, and the ‘back-to-coal’ movement (more progressively to be described as a ‘forward-to-coal-products’ movement), have led to an intensive scientific investigation of tar road construction.

For the purpose of development and progress the tar industry organized the British Road Tar Association as a propaganda and co-ordinating body with powers to initiate research, and its activities have been vigorous, both nationally and internationally. Early in its life it launched a vigorous advertising campaign of the patent medicine type, which was doomed to failure. This was followed by a more restrained and educative propaganda, and—above all in importance—a vigorous programme of research.

There is a Tar Research Committee of the Department of Scientific and Industrial Research, which is in the closest touch with the Department's Chemical Research Laboratory at Teddington, and with the Fuel Research Station. A deep study of the constituents of tar, and their effect on its properties has been made.

Grouting is being looked upon as being useful mainly in the maintenance of light traffic roads.

Tar *adheres* strongly to mineral aggregate, and the failure of a road-tar surfacing seldom results from the lack of it. Some quartzites and gravels present difficulties (as they do towards bitumen); and its behaviour with clinker, slag, and Portland cement must be carefully watched.

The *choice of viscosity* of tar for its particular purpose is guided by the nature of the stone, the time of year of construction, and the interval of time between mixing and rolling, as well as temperature and humidity during the period of storage and transport. The following figures show the diversity of requirements, justified or imaginary, of the quality of tar for various conditions :

Road-stone.	Viscosity of Tar in secs.	
	A.	B.
Slag	{ Hard 35-50 Soft 20-35 }	30-40 summer and winter
Limestone	Hard 25-35	{ 100 summer 50-60 winter
Granite	45 upwards depending on the tar	200

It is said that no difference in the quality of the tar is made for coating granite or syenite, but a larger quantity is required with the latter.

The variation of viscosity with the size of chippings to be held has been recommended to be :

$\frac{3}{4}$ to 1 in.	40-60 seconds' tar
$\frac{1}{2}$ to $\frac{3}{4}$ „	25-35 „ „
$\frac{1}{4}$ to $\frac{3}{8}$ „	15-25 „ „

When sent by rail, a low viscosity is used, so that the mixture may be usable after 7 to 14 days or even longer periods. It is the considered opinion of some that the necessity for varying the viscosity of the tar when used with various types of rocks is exaggerated.

In some ways the *tar-stone relationship* is more complicated than it is in the case of asphalt. At present seven sizes of coarse aggregate may be demanded ; each is graded separately, and subsequently mixed in the desired proportions before tarring. This ideal was achieved by an important quarry, but advantage was not taken of it by 'the practical man'. Minimum voids is not always aimed at, a more open texture being sometimes desired.

Tarmacadam and Tar Concrete.

Nomenclature. The Ministry of Transport uses the term 'tarred macadam,' whilst the industry refers to 'tarmacadam.'

For a long time past the terms 'Tarmacadam' and 'Tar Concrete' have been used alternatively (the latter but little) ; but recently there has been an attempt to differentiate between them along the following lines : *Tarmacadam*, a mixture of pre-coated broken stone which is transported and laid cold, or is produced by grouting ; *Tar Concrete* is a term that is no longer used. The B.S. Glossary (892 : 1940) divides 'Tarmacadam' into (a) Ordinary, (b) Semi-hot, and (c) Hot Process.

Composition. The mineral aggregate employed is usually limestone, quartzite, slag, or granite or similar rock.

One of the oldest tarmacadam roads still existing is Clarkehouse Road, Sheffield, which was probably laid in 1893. It has had only a few surface dressings, and "is still quite satisfactory."

Tarmacadam is to-day controlled by three standard specifications : B.S. 802 : 1945, dealing with granite, limestone, and slag aggregates ; 1241 : 1945, dealing with gravel aggregate ; and 1242 : 1945 for foot-paths, playgrounds, and the rest. They take the place of Wartime Road Note, No. 7, 1943 (superseding No. 1), which revised recommendations for tar carpets.

Experimental work done in Sheffield by Mr. Miller of the City Engineering Dept.⁹ has led to the laying of a mixture which is very different from the B.C. specification, and yet gives satisfaction.

The comparative compositions are shown in the table on p. 162.

This is a good instance of the absence of oppression in the influence

	Tar Asphalt (Sheffield).	B.S.S. No. 1241 : 1945.	Road Research Laboratory Wartime Note, No. 1.
	%	%	%
Passing $\frac{3}{4}$ in. B.S. sieve	—	100	—
" $\frac{1}{2}$ " " " "	—	90-100	95-100
" $\frac{3}{8}$ " " " " "	—	60-80	60-90
" $\frac{1}{4}$ " " " " "	100	—	40-55
" $\frac{1}{8}$ " " " " "	96-98	25-35*	25-30
" 14-mesh	44-66	—	15-25
" 52- " " " " "	17-29	—	10-15
" 200- " " " " "	8-12	3-7	5-7
Binder Content, % by wt. of total mix	10.0	6.5	6.25
Viscosity of Binder : E.V.T. . .	45° C.	37-40° C.	41-43° C.

* At least 40% of this material should pass No. 14 mesh.

and working of the British Standards Institution and the manner in which their standards are accepted and employed.

It will be remembered that a warning has been given elsewhere against too dense tar-stone mixtures, as these tend to keep the tar soft.

It has been realized that the main early disadvantage of tarmacadam, as compared with asphaltic macadam, is that it remains comparatively unstable for a long period. Under slow-moving horse-drawn traffic this was not very important, as during the hardening process the road was gradually consolidated by the traffic, and ultimately became fit to carry almost any load. Tarmacadam roads of this kind laid many years ago are still in good condition, and satisfactorily carry even present-day traffic. Research has been directed to the production of tars with a high melting-point, so that the hardening process may be more rapid, and the finished road may become capable of resisting the movement of traffic in a shorter period.

Tarmacadam laid hot has been tried with a fair measure of success, and is a type of material that may be found to be able to carry the heaviest traffic.

The use of mechanical tests in directing the design of dense tar surfacings is proving to be of great value⁵⁴; so far practical results on the road substantiate the laboratory experiments, surfacings bearing very heavy traffic have been produced⁵⁵.

The ageing of tar surfacings through the evaporation of constituents has been elaborately investigated,⁵⁶ and found to be a difficult matter to study and measure, owing to the variability of conditions and the sensitiveness of the tar to them. One practical but only approximate result was that, for experimental purposes, 12 days' heating at 50° C.,

under laboratory conditions, was equivalent to 1 years' ageing under working conditions.

In addition to evaporation, polymerization and oxidation also have important effects which must be considered in connection with the behaviour of a tar under road conditions ¹⁷⁸.

For over 8 years trials were made in the use of *metal reinforcement* for tarmacadam surfacing. The first notable attempt was probably that of H. G. Henderson, of the Truro School of Mines (B.P. 25, 124 : 1909), which was not a success. It has not been developed as it has been found to be unnecessary.

The difficult conditions during the war led to Departmental recommendations regarding tar carpets and surface dressings ⁴³⁸.

Thin Carpets

The position in popular favour of the classical design of asphalt and tarmacadam surfacings has been attacked with increasing vigour by thin carpets the characteristic of which is a small-sized aggregate. It may be made hot and laid warm or cold.

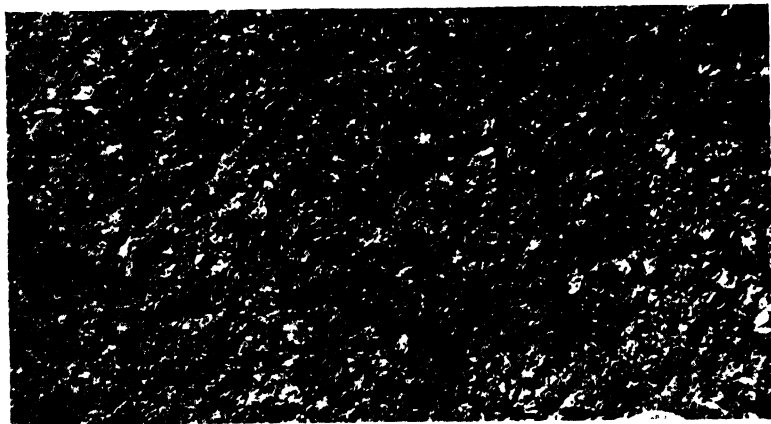
Surface Treatment.

The first serious experiments in surface tarring were carried out by Dr. Guglielmenetti on the Riviera, in 1901, but only in 1907 was there any substantial improvement, as a result of the activities of the Roads Improvement Association.

It is remarkable that even after this long experience surface tarring was still looked upon by a few as being a fool-proof process that required little attention. For this reason the British Road Tar Association issued a series of Publications.

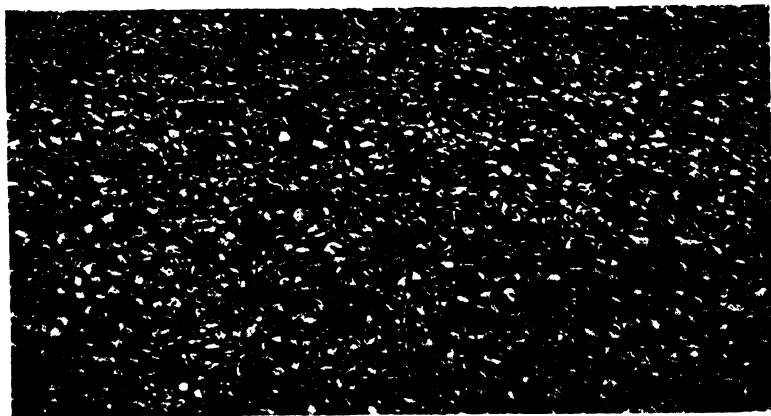
The chemical composition and the nature of the stone controls the choice of tar : the harder and tougher the stone the higher must be the viscosity of the tar, which should be heated to between 220° and 240° F. If tar of Type A, B.S. 76 : 1943 be selected for use, only the viscosity need be considered by the user. It therefore becomes possible, on two charts, to correlate traffic and atmospheric conditions, with viscosity, so as to give the best temperature for spraying, rate of spreading, previous history of the surface, type of aggregate, and required thickness of film ⁴⁴⁸. The best method for distributing the tar over the road surface is not yet settled. In order to take full advantage of the fluidity of the tar and of the slight softening in the case of underlaying tarmacadam by its heat, coarse grit or chippings must be immediately and generously spread and rolled in. Two examples of surface treatment with tar are seen in Figs. V.8 and V.9.

There sometimes used to be a desire to build up a surface carpet by means of yearly or more frequent treatment with tar and chippings, independently of whether such treatment is necessary. Such a layer



By the courtesy of the British Road Tar Association.

FIG. V.8.—Surface Treatment with Tar. Slag Chippings: after 12 months of fairly heavy country traffic.



By the courtesy of the British Road Tar Association.

FIG. V.9.—Surface Treatment with Tar. $\frac{3}{4}$ -in. Granite Chippings: after 18 months of fairly heavy country traffic.

may become 2 in. or more thick, and may lead to serious pushing and wave formation.

The penetration of tar into surface pores of capillary dimensions is controlled in part by the free carbon present, as this may protect the mineral matter against the entry of the tar ¹⁶⁶.

Tar Grouting (Penetration).

The mineral aggregate— $2\frac{1}{2}$ – $\frac{1}{2}$ in.—is first lightly rolled, then dressed with chippings and re-rolled. Penetration is usually carried to a depth of 2– $4\frac{1}{2}$ in. by means of soft coal-tar pitch, after which the surface is gritted and finally rolled.

Tar-Bitumen Construction.

This designation is not strictly in accordance with the decisions of the International Committee on Nomenclature, but is convenient whilst being unequivocal.

The use of such a mixture, containing up to 20–25 per cent. of bitumen, is reserved for the base coat in two-coat construction, especially in Scotland, where temperatures are relatively low. It is also used for tarmacadam and grouting mixtures. In tar-bitumen macadam surfacing the mineral aggregate is similar to that used with tar alone.

Pitch-Bitumen Construction.

A mixture which deserves mention on account of its interest—though it is by now obsolete—consists of blast-furnace or coal-tar pitch and ‘pure bitumen.’ The pitch had a twisting-point of 40–65° C. and both a softening-point of 72° C. The pitch heated to about 220° F. and the bitumen to about 320° F., they were mixed, and then 80–90 per cent. of $\frac{3}{4}$ – $\frac{1}{4}$ in. chippings were added. The whole set to a tough and non-skid surfacing. This toughness is due to mutual precipitation of the two bituminous substances which causes the formation of desirable properties; different from the two components ²⁵⁹.

If the above explanation be the true one this type of construction actually exploits that segregation that is so serious a defect when met with elsewhere.

Tar-Rubber mixtures have been made. Unvulcanized or vulcanized rubber can be introduced into dephenolated tar, or pitch, by previous solution in oil; or by homogenation of latex with tar ⁴¹². This discovery seems to have had no useful application; but tar-rubber mixtures for *surface dressing* have been tried in Germany, with increasing production between 1933 and 1937. Rubber waste was mixed with tar in the proportion, roughly, of 5 to 65 ⁴⁰⁶.

Cold asphalt has been described on page 153; the hot mixture contains mineral aggregate of granite or gravel from $\frac{3}{4}$ in. downwards, and has been most carefully investigated at the Road Research Laboratory on a scale that was “the most extensive that had been carried out anywhere in the world on bituminous road surfacings” ⁵³¹.

Cotton and Jute Fabric Reinforcement.

Coarse cotton fabric is still being tried as a reinforcement and stabilizer for bituminous road surfacings ; and as a separating medium for keeping apart two layers of concrete or a road surfacing and its foundation, so as to facilitate future reinstatements. The idea originated in America about 1927, and some success was attained ^{335, 375}.

In this country, a trial has been made in Burnley ²³² (Lancs.) when surface dressing a newly laid water-bound road. The cotton fabric used weighed about $4\frac{1}{2}$ oz./sq. yd., and consisted of about sixes twists and weft. Jute has been examined for this purpose, and although the indications were not hopeful ¹⁶¹, trials were made in Dundee with local, German, and Calcutta specifications ³⁸⁰.

This process does not appear to have done well in this country, owing to the adverse effect of unfortunate local conditions or of details other than those associated with the use of the fabric itself.

(See also 230, 389, 390, 391, 392, 455.)

The nearest to this type of use has been a prefabricated bituminous surfacing consisting of jute hessian coated with a filled blown bitumen, edge-to-edge joins being made by the application of petrol. This has had considerable success for airfields in France and Belgium.

PLANT

Two main types of plant have been established that differ primarily in size and weight : *stationary*, from which the product may be sent as far as 50 miles in suitable vehicles ; or *portable* (sometimes called *mobile*), which is relatively easily transported and re-erected on the site of the work. There has been continuous development of these.

A later development is the completely *mobile* plant, which collects the mineral aggregate that has been previously laid along the road to be surfaced, mixes it with bitumen and pours it out in front of a spreader-tamper. This is in use in America ⁸² and has been worked in this country. It is claimed to have advantages in saving the expense of long-lead transport, freedom from exact timing of deliveries, and wear and tear of road surfaces travelled over. (See also p. 174.)

Plant for producing bituminous mixtures is so well known that comments, rather than a description, need be given.

Hot Mix. The plant that will produce hot asphalt is so closely similar to that employed for tarmacadam, that for the present purpose they can be described together. This statement must be modified for large-scale continuous output of tarmacadam, in which the drying drum may have to be 30 ft. long so as to dry a material such as slag

at a relatively low temperature. The tar is sprayed on to the mineral aggregate to the correct amount ascertained by a short preliminary working. Stationary plants have an output of up to 300 tons a day; portable plants can supply from about 4 to 40 tons a day, rated on a moisture content of the aggregate of 6 per cent. Plant has been further specialized for the production of thin carpet surfacing.

In principle, the mineral aggregate is carried from the boot by the cold elevator to the drying drum, and then by means of the hot elevator to screens that separate it into coarse and fine aggregate which are stored in two different hoppers. Each then passes, in weighed proportions, into a mixer, where the proper quantity of filler and bituminous binder are added. After mixing the mixture is discharged downwards into lorries (Figs. V.10, V.11, V.12 and V.13. Another form of plant is shown in Fig. V.14).

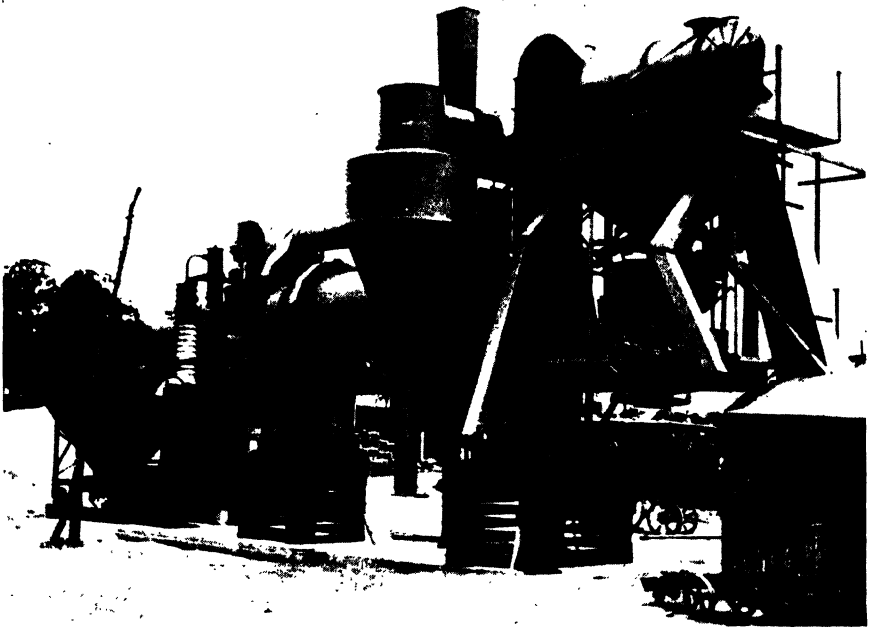
Stationary Plant.

Cold Elevator. This usually consists of two chains carrying a succession of buckets at spaced intervals; or a succession of buckets hinged together. Provision, as by some kind of friction clutch, should be made against jamming and consequent fracture of the elevator and stoppage of the plant. An automatic control has been devised to regulate the quantity of aggregate entering the drum, so that the flow shall be regular.

Drying Drum. This is usually cylindrical in shape, and provided with some sort of internal projections or scoops which cause a progressive tumbling motion to its contents. It may be provided with baffles to prolong the contact of the material with the hot gases. The drum can usually be adjusted as to its angle of tilt according to the desired rate of passage of the material through it, and this to the amount of moisture present and to the desired output. Or the drum may remain horizontal, the contents being driven through it by the force of the weight of the entering aggregate.

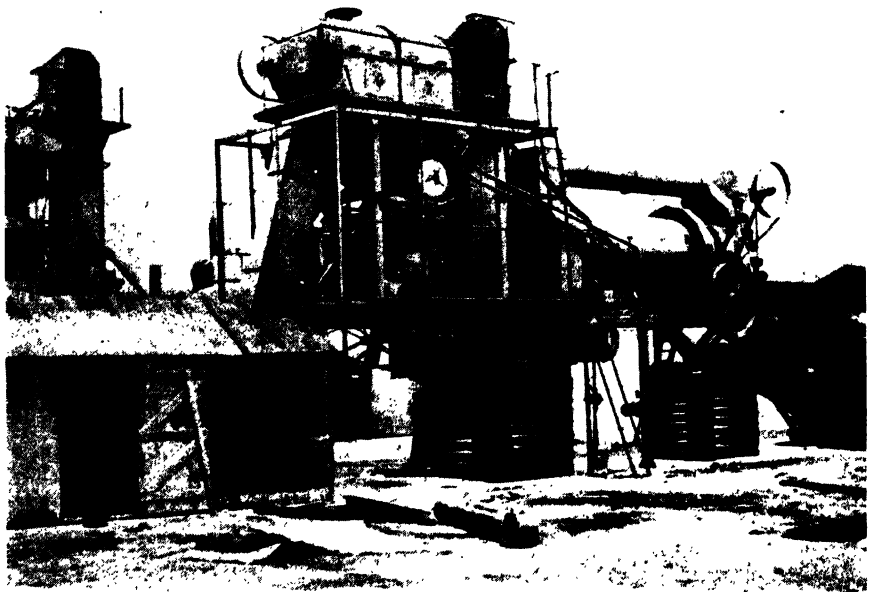
Drying is effected by heat generated by coal, coke, or oil, and the hot gases are led through the dryer in the same or contrary direction to that of its contents. Arrangements should be made for the admission of large volumes of air, for cooling the hot gases to a desired temperature, and for lowering the cost of drying. Extra rapid drying has been achieved by arranging for the entry of fresh hot gases at several points along the drum.

For economy of space, the long cylindrical drum is sometimes replaced by contracted or vertical dryers that make up for their shortened length by some mechanical means (Fig. V.15). For instance, in one case, there is a series of circular plates, fixed to a vertical shaft,



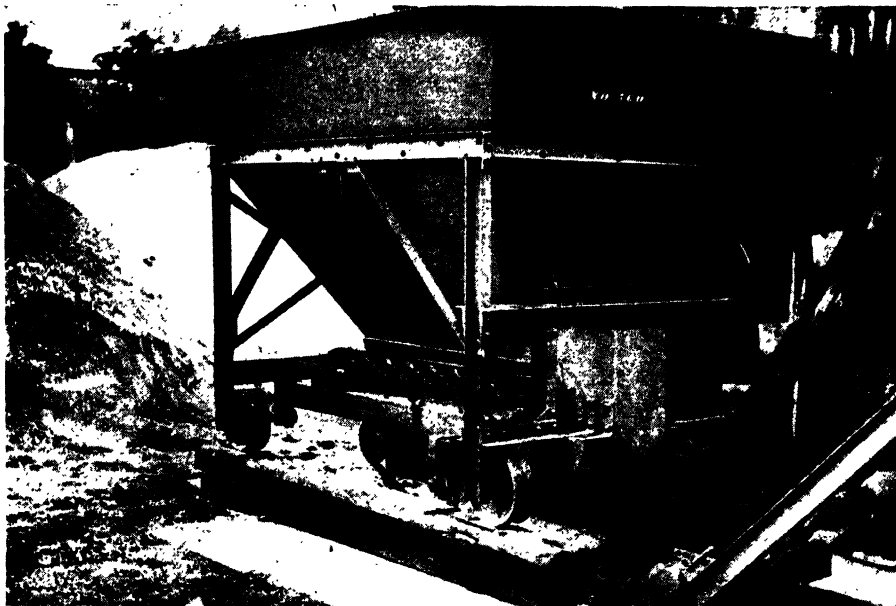
By the courtesy of Millars' Machinery Co., Ltd.

FIG. V.10.—10-Ton per hour Dual-Purpose Asphalt-Plant —wheels removed— showing Aggregate Feed Hoppers, Elevator, Drying Drum, Cyclone Dust Collector, Aggregate Storage Bins and Mixer Platform.



By the courtesy of Millars' Machinery Co., Ltd.

FIG. V.11.—Same Plant as in Fig. V.10. from the opposite side.



By the courtesy of Millars' Machinery Co., Ltd.

FIG. V.12.—Aggregate Feed Hopper, 4 cu. yd. capacity, delivering aggregate in separate quantities with the buckets avoiding scooping out of a sump.



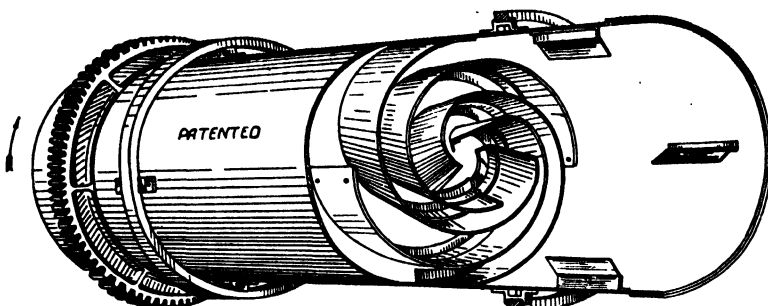
By the courtesy of Millars' Machinery Co., Ltd.

FIG. V.13.—Enlarged View of the Mixing Platform, with weighing gear for Aggregate Filler—separate weighing-room provided for bitumen.



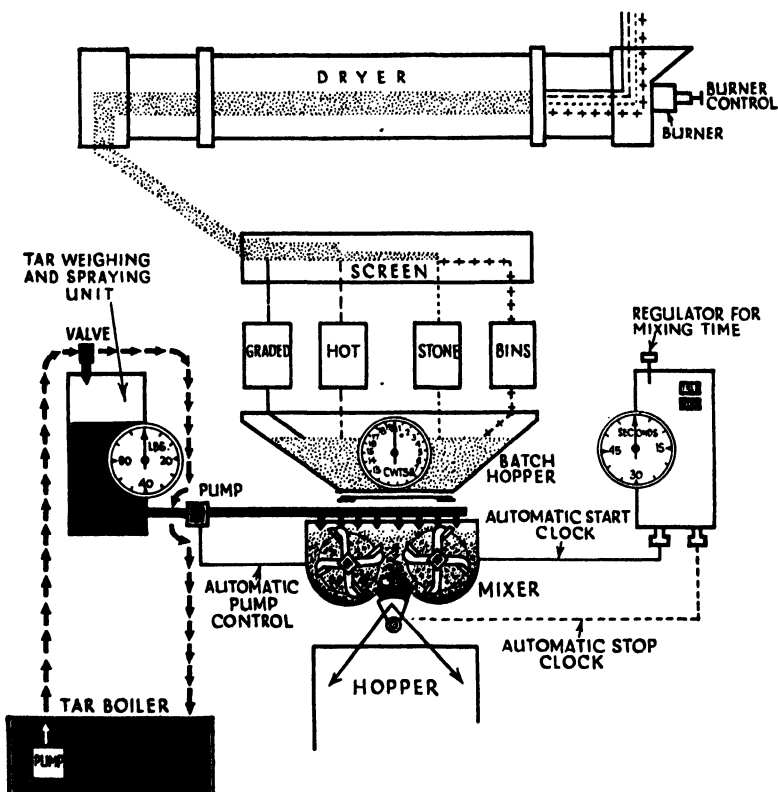
By the courtesy of Bristow's Machinery Co., Ltd.

FIG. V.14.—Bitumastic Macadam Plant, showing Dryer (in background), elevator to screen and bins above, mixing platform, and storage bins for coated material.



By the courtesy of Messrs. Johnston Bros. (Contractors), Ltd.

FIG. V.15.—Drying Drum.



By the courtesy of Messrs. Pegson, Ltd.

FIG. V.16.—Diagram of a Tarmacadam or Asphalt Mixer and Feed of materials, and Indicator for Time of Mixing which can be set to make one revolution of the pointer for a given mixing time.

which revolves at such a speed that the material entering from the top is thrown outwards by centrifugal force to the edge of the first plate, from where it passes to the centre of the next lower plate, and so on to the exit. In another, simple gravitation through louvres, or along a series of conical surfaces, carries the wet aggregate counter-current to the stream of hot gases.

Heating. Oil firing has become increasingly popular on account of the very regular temperature that can be obtained, particularly when an automatic control is installed. Such an advantage may easily outweigh any increase in cost or trouble with barrels at a temporary plant—a cost that is more than balanced by uniform excellence of output.

Weighing Device. This consists of a beam or dial weighing mechanism, by which the tare and separate and combined weights of the aggregate can be successively determined; as well as the weight of the bitumen when this is not measured by volume. The zero and general accuracy of the machine should be ascertained at least once a day. An example is shown in Fig. V.16.

Bitumen Pump. This draws the hot bituminous material from the tanks into the weighing bucket, and circulates it back to the tank when not required. It should be capable of acting reversably, so as to empty the system at the end of the day's run, through drainage cocks.

Sometimes a pneumatic lift is employed.

In the case of certain tarmacadam mixers, the tar is sprayed into the mixer.

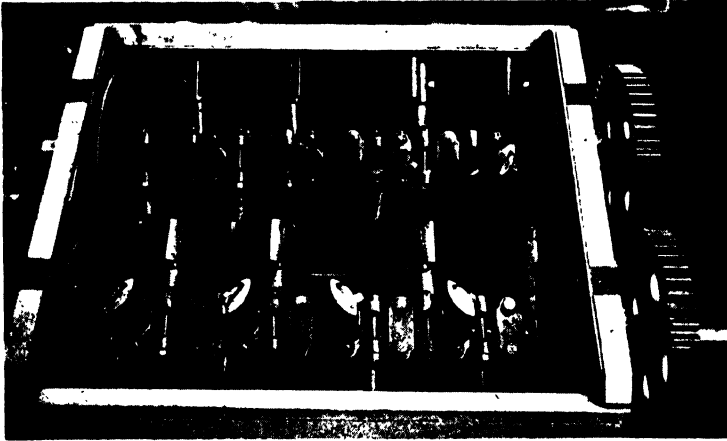
Mixer. According to the quantity of material to be handled the plant is provided with a single or double shaft mixer (Fig. V.17); for fine mixtures a two-shaft is preferable. Both may be installed in one plant and used according to requirements; but a two-shaft mixer has been constructed to deal with all grades of mixtures. Mixing may take 2–4 minutes according to the size of the batch.

The setting of the paddles on the shaft determines whether the material should be brought to the middle and then round the sides, or whether it should be continuously chased round the mixer.

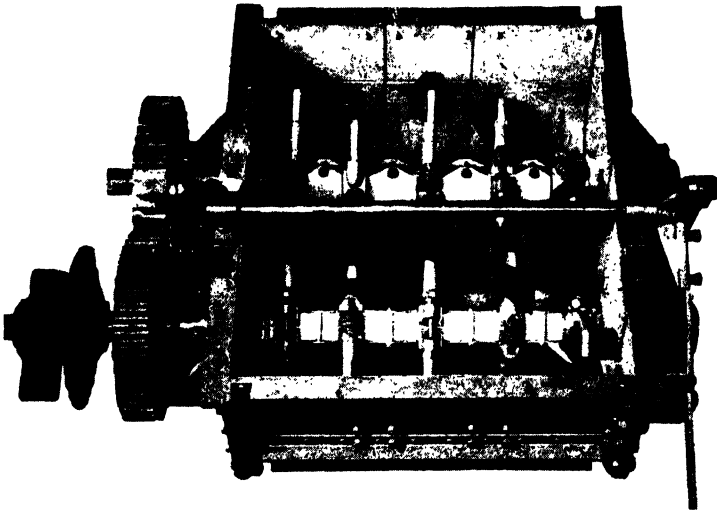
There has been a drastic re-examination of the details of asphalt and tarmacadam plants. The drying drum and shafting run on ball bearings; large-capacity exhaust fans are favoured; solid and pneumatic tyres are replacing iron ones; and further improvements are appearing, such as in weighing devices.

As an example of the plant of to-day, the 10-ton per hour semi-portable dual purpose asphalt and tarmacadam plant of Messrs. Millars' Machinery Co., Ltd., may be quoted, together with certain details to be considered in addition to the general description of such plant just given.

For successful high-temperature work the aggregate should not contain more than 6 per cent. moisture, and the temperature should be 350° to 450° F.; for low temperature work these figures should be 4 per cent. and 100° to 150° F. respectively.



By the courtesy of Messrs. Stothert & Pitt, Ltd.



By the courtesy of Millars' Machinery Co., Ltd.

FIG. V.17.—Two Examples of Twin-shaft Paddle Mixers.

The aggregate is fed into the individual buckets of the elevator and not into a pit from which the buckets scrape up their loads.

The drying drum is lagged with an asbestos mattress.

The various quantities of components are weighed in a hopper

with a dial indicator. The bitumen is drawn by a rotary pump into a measuring tank. It is a matter of constant discussion whether bitumen should be measured or weighed. Weighing is more consistently accurate as it is independent of temperature and its expanding effect on the bitumen ; but measuring is more convenient. 30 h.p. are required to drive the plant.

Power and Power Transmission. Statements concerning the power required to drive the various types of plants are too divergent for any generalization to be made about them. It has been said that an asphalt plant, delivering 10 tons an hour, requires at least 16–18 h.p. ; and a tarmacadam plant, delivering 7 tons an hour, requires at least 8 h.p. Also, that according to the rating for steam or electricity, the figure must be increased for internal combustion engines. In all cases it is important that ample power should be available.

All transmission is by chains or gearing, except that a belt is often used between the plant (at the mixer end) and the prime mover ; sometimes also for driving the fan.

Control. Complete control of the mechanical working of the plant should be within easy reach of an operator on the mixer platform.

Thermo-indicators, mounted so as to be uninjured by vibration and flying dust, should be installed to show the temperature of the aggregate descending into the mixer, and of the bitumen arriving at the bucket. In both cases the thermocouples, or mercury-in-steel distance thermometers, or the like, should be in the direct stream of the materials and not in any side pocket. Such means of temperature measurement and record are more satisfactory than the ordinary mercury thermometers, as being less fragile ; and once the first cost has been met, continuous satisfaction may be expected. The zero of indicating or recording apparatus should be checked at least once a day.

Bitumen Tanks. These range from 320 to 2,500 and 3,500 gallons. A service tank of 15 gals. is advantageous.

The design should minimize the chance of injury to the material by too severe local heating, or of inequality of temperature throughout the mass. In the larger sizes steam heating may be desirable.

Construction. The construction, thus outlined, is capable of many refinements of detail, such as the use of special steels at particular points of the plant, automatic weighing, heating of mixer by hot gases from the dryer, prevention of escape of dust, etc.

Portable Plant.

Modification of design is required only for convenience of transport, and ease of re-erection. Rubber wheels are used to lessen wear and

tear ; the whole plant may be mounted on springs, with wheels adaptable to the camber of the road. Some minor details, such as a bitumen hoist in place of a bitumen pump, may be varied.

Mobile Plant.

One of the first complete mobile plants in this country ²⁴³ is that shown in Fig. V.18, and an example of its work in Fig. V.19 ; but the British adjustable spreader, towed by a lorry, and more suited to our smaller-job conditions is that of Ransomes & Rapier.

The most notable advance among several has been the Barber-Greene plant, devised in America as stationary and mobile plants. The most highly developed of the latter consists of a mixing plant connected with a mechanical spreader ('finisher'), and is automatic under the hand of a highly-skilled puller of levers. A type has been designed that is suitable to British as compared with American conditions. A maintenance type is available for small jobs.

The two main points of difference from British principles is the projection of bitumen from jets on to the mineral aggregate on its way to the mixer, and the batching by bulk instead of by weight. The fact that this method of proportioning does work is evidence in its favour, but the possibilities of irregular results are obvious ; but it is claimed that these do not occur.

Another plant of the same general type is the Adnum Black Top Paver, a newer-comer into the industry.

Both spreaders work at about 35 h.p.

Batch Drying and Batch Mixing. The conventional plant which has been discussed above, based on continuous heating and batch mixing, is designed for producing bituminous surfacings under normal conditions. When working is restricted in space or desired output, and when temperature requirements are not unusual and the moisture content of the aggregate is not high, batch drying and batch mixing may be advantageous.

There is no cold elevator, the aggregate being raised and tipped into the dryer. The dryer gives an exaggerated tumbling motion to its contents, so that moisture may be expelled in about 4 mins. The hot material goes directly into the mixer, which is of the same type as is employed in the larger plants, or may resemble a concrete mixer. (See also ⁵⁹⁰.)

Periodic overhaul is necessary for the maintenance of efficiency ; apart from any evidence of bad working indicated in the routine analyses.

Transport. The transport of asphaltic material from the plant to the road must be effected with as little loss of heat as possible

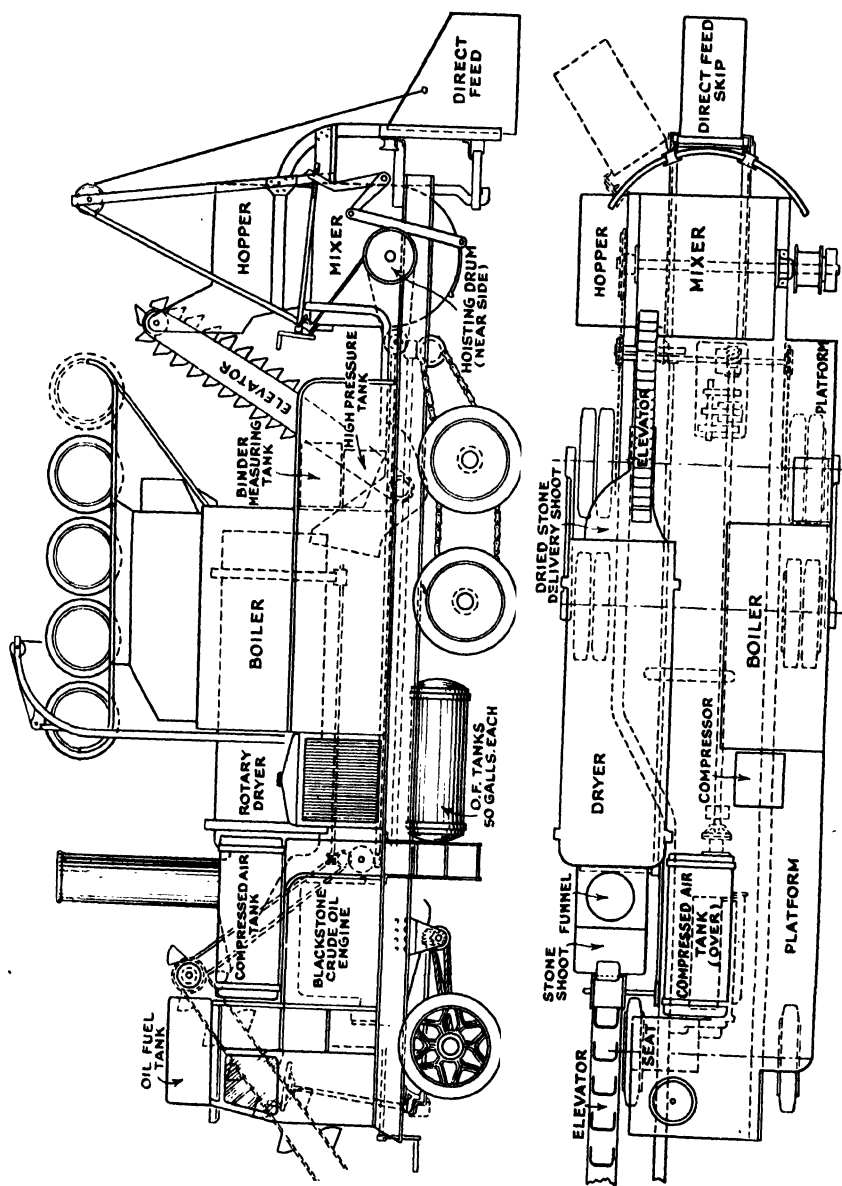


Fig. V.18.—Mobile Bituminous Roadmaking Plant (Patent).

(see p. 147). It has been found that a load starting at 340° F. lost 10 per cent. of its heat after travelling 25 miles. This is about the limit of 'tarpaulin insulation'; for longer distances, and as an insurance against loss and inconvenience resulting from setting, air insulation or even steam heating is worth the trouble and expense.

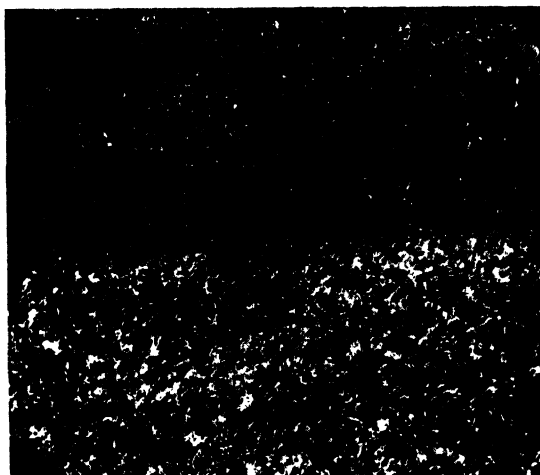


FIG. V.19.—Showing Two Surfacing and their Intimate Joint, laid by machine shown in Fig. V.18.

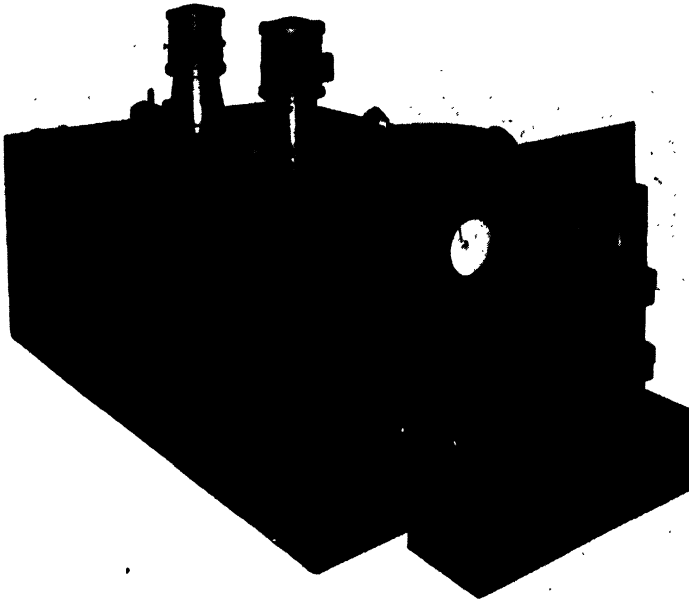
Bitumen and Tar Boilers.

This looseness of ascription is to be deplored, in that the boiling of these materials is the last thing that is desired.

For the purposes of this book it is not necessary to consider such plant in detail. It is sufficient to say that the industry is well supplied with a wide choice, from 50-gal. heaters up to 2,000 gals. or even larger, some being provided with stirrers. They can be heated with coal, coke, or oil, and in some cases the hot contents are protected from the chill of an incoming cold charge.

A remarkable advance in the heating of these boilers is the use of electricity ⁵⁹¹ which, with thermostatic control and circulation by pumps, ensures the supply of a uniform quality of material at a uniform temperature. The latter is facilitated by an electrically heated jacket for use in exposed positions. Expense is kept down by the delivery of the material hot from the distillers; but in any case "the cost of heating the binder with this boiler is much lower than with steam." According to the size of the boiler and to local conditions, 70–100 units of electricity may be used in 24 hours. Maintenance is claimed to be very low over long periods (see Fig. V.20).

A warning may here be given against overheating, which may easily occur, especially when small quantities are being handled. White vapours may be taken as indicating that residual moisture and volatile



By the courtesy of the Clarmar Engineering Co., Ltd.

FIG. V.20.—Two pumps control two independent circulating systems, each with reversing type of starter (on right-hand side); hinged man-hole on top right-hand side. Recording thermometer controls temperature electrically.

oils are being driven off, but blue vapours are a sign of damage or destruction to the bitumen. There is no external demonstration of the gradual hardening that takes place during prolonged heating at temperatures below which damage occurs. This can, to a great degree, be avoided by the use of primary and secondary heating—the bitumen is first rendered fluid, after which it flows to the boiler proper.

Mastic Cookers, Compressed Asphalt Roasters; Sand and Stone Dryers.

The same looseness that was referred to in respect to bitumen boilers is justified here also as regards 'roasters.' This term is usually associated with considerable change in chemical composition produced by heat (as for instance in the case of meat and coffee); and if such a change occurred with powdered rock asphalt, the ultimate road surfacing would have little value.

The main interest in mastic cookers lies in their stirring arrangements and the enormous length of time that is considered necessary for successful operation. It would seem that a valuable investigation could be carried out to reduce the minimum of 5 hours required for good mastic to be produced. The power required to drive them, by petrol engine, is about 3 h.p. for 30 cwt. size to about 8 h.p. for a 9-ton mixer. There are several self-contained models designed to travel under their own power, some on rubber tyres.

There is little to say about the sand and stone dryers, except that a good range of them is available. It might, however, be questioned whether they are as economical in heat as they might be. An attempt has been made at all-round economy in fuel and upkeep by heating the hot plate with a close steam coil system and lagging it with slag wool ²¹⁴. The principle is claimed to be suitable for tar and bitumen heating.

MAINTENANCE

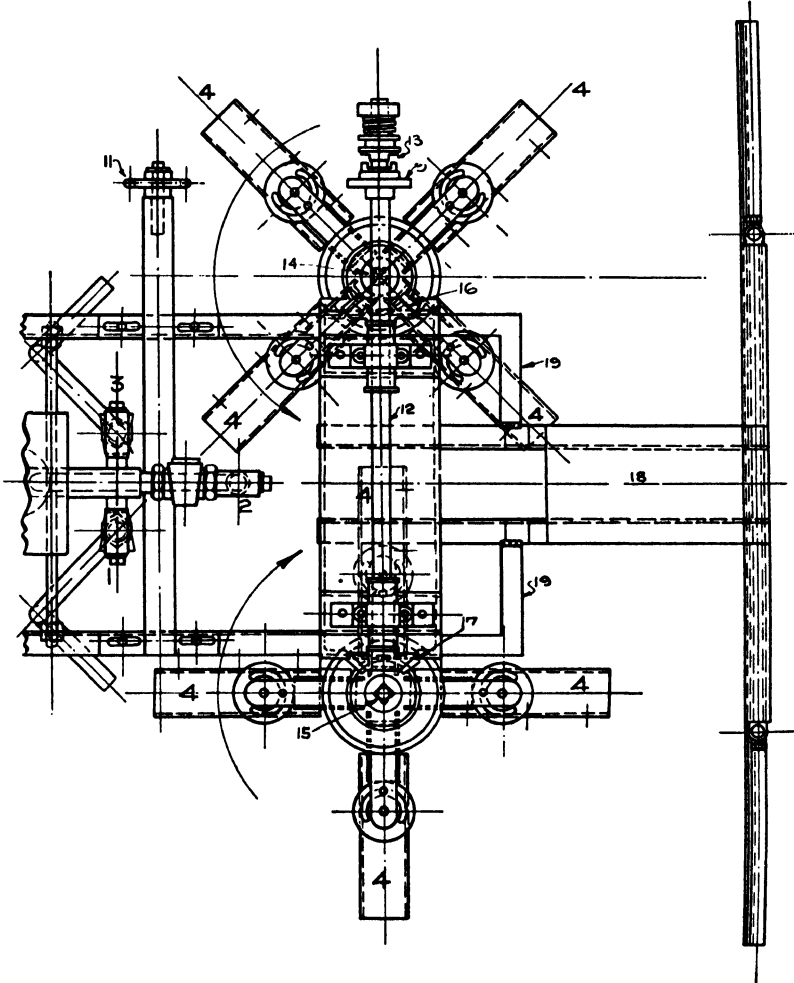
Surface Treatment.

For the last-mentioned purpose the bituminous material must be of such a character that it will hold grit or chippings of the required size. At the same time, neither the quality of the bituminous material nor the quantity used must be such that it will 'fat up' under the traffic or high temperature to such a degree as to submerge the mineral matter.

There is a large number of proprietary materials that cannot be referred to in detail for reasons given in the Preface, but it is not difficult to find them ¹⁶⁷. Many consist of specially treated asphaltic bitumens and tars, and many are tar-bitumen mixtures; often with added fillers. Such treatment was first given to road surfaces to allay dust; and it was found that considerable improvement of the surface itself resulted. Later, when both motorists and horse owners clamoured for a rough surface, surface dressing was developed and provided a cheap and quick method; but as in all other such matters the cheapest is not always the best value. (See also ²¹⁰.) In addition to satisfying these requirements, surface dressing greatly prolongs the life of the surfacing.

Such surface dressings are valuable to the road engineer for making good an otherwise doubtful surface or prolonging the life of a satisfactory one. They may be applied hot and squeegeed or brushed by hand or mechanically (Fig. V.21); or may be used cold, as emulsions or cut-back bituminous substances. Application is frequently done by spraying.

The employment of surface dressings is known to all engineers ; but attention might be drawn to those cut-back bitumens, and bitumen solvents in form of emulsions, which are used for the temporary



By the courtesy of Messrs. Johnston Bros., Ltd.

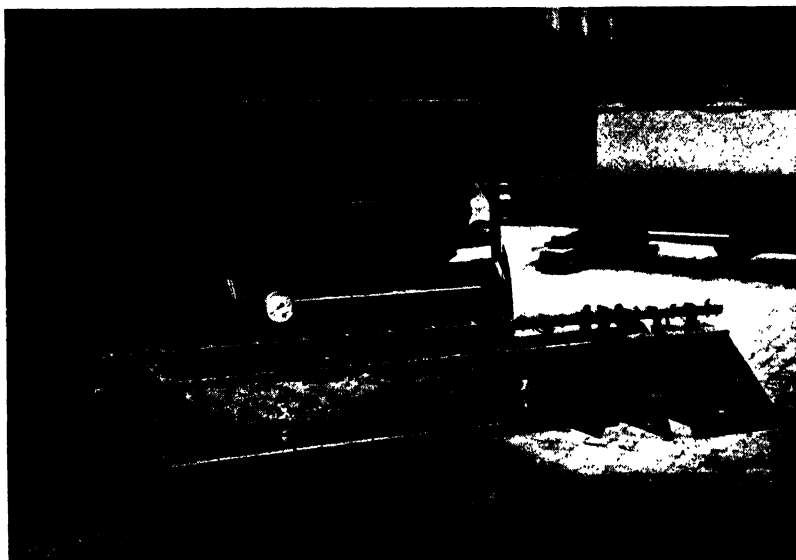
FIG. V.21.—Mechanical Brush Gear for Tar and Bitumen Dressing.

* Vertical shafts 14 and 15 are driven by bevel wheels 16 and 17, mounted on another shaft 12 which receives its motion from the road wheels of the boiler through a chain drive and clutch 9, 11, 13. Liquid is discharged through the cocks 1, 2 and 3 to the road immediately in advance of the brushes 4 (eight in number), which are rotating horizontally over the road surface at the base of the shafts 14 and 15, four to each shaft. The speed of rotation of the brushes is in proportion to the speed of travel of the boiler and every particle of the road surface is brushed nine times.*

softening of an asphalt surfacing for the better reception of chippings, etc. For one of these it is claimed that 70 per cent. of the solvent disappears in 12 hours, and that the whole has gone within a month

(according to circumstances); and that chippings are held within an hour.

There is a tendency to advocate the use of the largest possible size of chippings, but it is doubtful whether this is either necessary or desirable. Excellent results are obtained by the use of $\frac{3}{4}$ -in. chippings and smaller, and suitable material of $\frac{1}{2}$ -in. gauge is almost invariably large enough for all practical purposes. The very large material used in some places gives most uncomfortable riding, and is difficult to hold permanently in place. There is some danger in using anything above



By the courtesy of Messrs. Thompson Bros., Ltd.

FIG. V.22.—Elliptical Lugged 1,100-gallon Road Tank, with Sprayer.

$\frac{1}{2}$ -in. gauge in towns, as it is liable to be thrown about with great force by passing vehicles, and may cause unjustifiable wear on tyres. Immediately after the spreading of the grit or chippings, a roller should pass over the road and the mineral matter pressed into position.

In war-time, slippery roads have been treated first with an application of a cold solvent at 8 sq. yd./gal., and then with $\frac{3}{4}$ -in. precoated chippings (after 1 to 2 weeks storage) at the rate of 40–50 sq. yd./ton. After rolling, a light covering of sand-mortar was squeegeed into the surface ⁵²⁷. Attention should be drawn to *Wartime Note, No. 8, 1944*, revising recommendations for tar surface dressings for a number of different surfacings.

According to the scale of working, means can be selected ranging

from hand operations to an almost completely mechanical plant, and developments are continuously taking place.

Small-scale Operations. The simplest method of application is by pouring by *hand* and spreading over or into the surface by means of squeegees or brushes. *Tanks* up to 80 gals. drawn by hand, or up to 400 gals. drawn by horse or motor (approximately 5 h.p.), are supplied with hand-operated external pumps, or sometimes internal in the case of bitumen, working at about 40 lb. pressure. For hot material they may be fed with hot liquid or carry their own means of heating ; in the latter case, an anti-frothing device is desirable.

For *Larger Operations*, when the tank may be of 1,000 gals. and more content, more complete mechanical control is possible and necessary (see Fig. V.22). The plant now consists, essentially of a tank of hot material, a gritter, and roller (10–13 tons, 30–40 h.p.), and a tractor. These may be used separately, or they may be variously combined ; for instance, the roller may carry the bitumen tank, and act as tractor to the gritter ; or the bitumen tank (self-heating) may be mounted with or without the gritter on a chassis and be drawn by the roller. Or, again, the bitumen tank, heated with steam, may be carried by any suitable road wagon, and be removed when not required.

Such mechanization enables the pump, working at about 30–50 lb./sq. in., to be geared so as to deliver material in proportion to the speed of travel of the tank, whereby a uniform quantity per unit area of surface passes the nozzles. An air compressor may be used to force the liquid from the container.

When the roller is also tractor, after each run it returns and rolls the grit into place ; and according to the construction of the trailer, this may or may not have to be detached.

A notable substitute for pump-spraying is the ' Flapper ' machine ⁴⁴, where the filtered hot material falls by gravity through jets and is broken up by horizontal beaters (Fig. V.23).

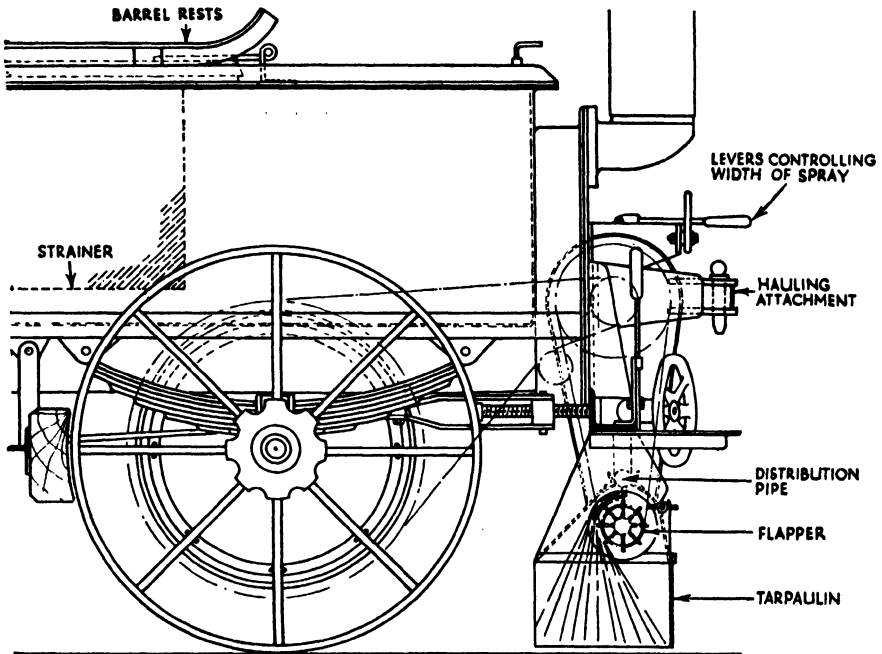
Gritting follows immediately after spraying, by means of a mechanical gritter carried by a 30-cwt. lorry, proceeding in reverse so that its wheels will not pass over the unblinded tar. The operation is reported to be technically excellent, expeditious, and economical ¹⁴⁸.

The *hose* is of special construction. It may be of metal, covered with asbestos, and this ultimately with rubber, and finally strengthened with wire. Or, it may be of rubber of a nature to withstand the action of hot tar for a reasonable time.

The *nozzles* are usually self-clearing, and may be adjustable to suit the viscosity of the material and the pressure employed.

Gritter. The gritter is essentially a travelling distributor and may

be hand or mechanically operated. The regularity of action depends on oscillating shutters, a spindle carrying short paddles, steel vibrators, revolving brushes, mechanical projector (Fig. V.24), or some other contrivance. It may be a separate machine, or fixed to the tail-board of a lorry; or it can be combined with the sprayer on one chassis, and work at about 4 m.p.h.



By the courtesy of Messrs. Thomas Colman & Co., Ltd.

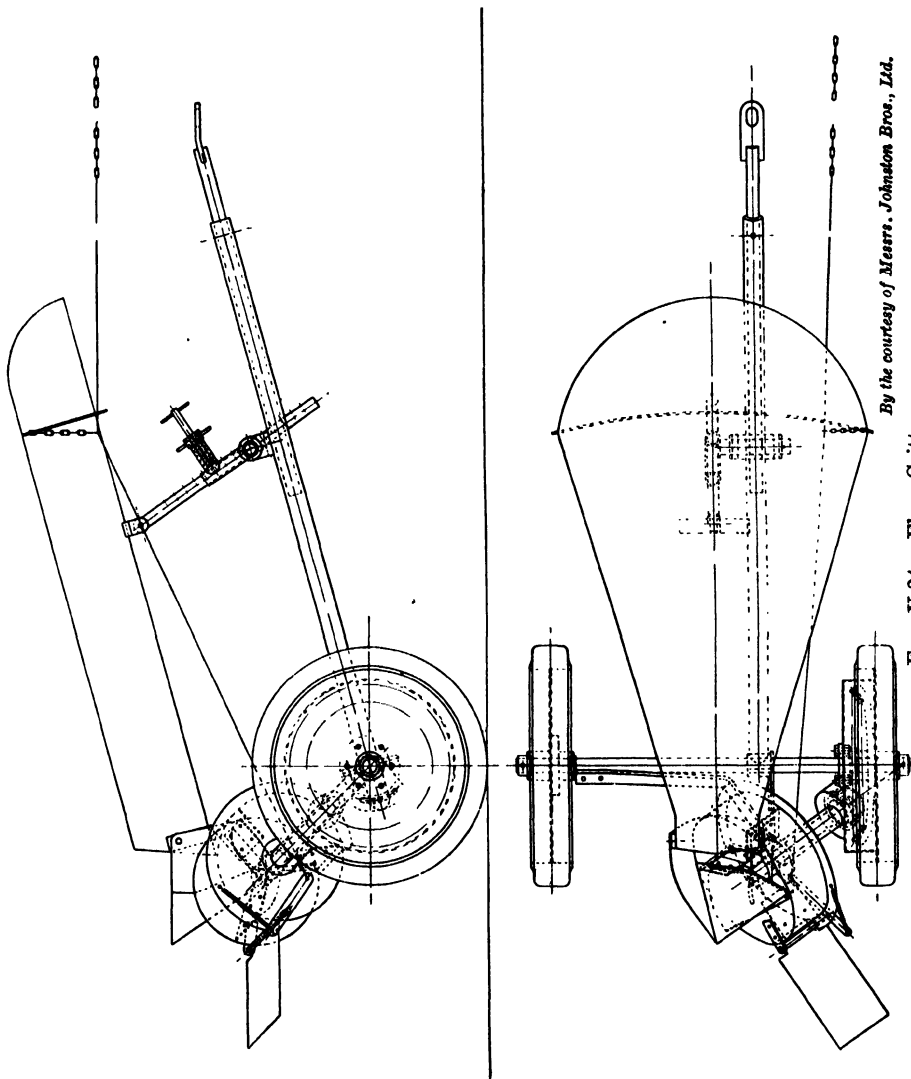
FIG. V.23.—Flapper Spraying Tank.

Another type of gritter works on the principle that large stones and foreign bodies become buried in the bristles of the brush which works the chippings out of the hopper, whereby streaks and irregular work are avoided ⁵⁹⁵.

Dust Laying.

Water-bound macadam and loose road surfaces require some means for retaining their dust for the sake of their stability, and for the comfort of the road users and the neighbourhood.

Suitable materials are water, with or without deliquescent salts (such as calcium and magnesium chlorides, which may also be used in powder form); tar and asphaltic bitumen of suitable types and



By the courtesy of Messrs. Johnston Bros., Ltd.

FIG. V.24.—Flyer Gritter.

methods of application ; sulphite liquors from wood pulp factories ; molasses and vegetable and animal oils—all are or have been used ⁶¹³.

Finally, the sprayer may be towed, and itself tow a combined gritter-roller.

Repairs.

Repairs may consist of anything between the patching of a pot-hole and the reinstatement of a trench, to the replacement of a whole area of weak surfacing ; as well as the reduction of excessive waviness or bumps.

Heaters are required for preliminary drying, for softening or burning off of the surfacing, or for heating tools. These may be heated with coke, oil, or petrol ; and some dual-purpose heaters have been designed.

These heaters range from the ' fire devil ' normally employed for heating compressed asphalt tools, and small petrol or paraffin fired furnaces, up to larger and more complicated contrivances.

The first machine of this kind was the *Greco* ¹⁹², which was received with much opposition by the ' big firms ' until they realized that it would aid and not damage their interests. In use, the worn asphalt or tarmacadam was softened so that it could be raked and mixed with new material, and rolled (very slowly) into position with firm adherence to the foundation. This was done by means of hot air ; it was claimed at a rate of 1,000 sq. yd. a day per machine.

Later machines were designed to give a fiercer heat, to burn off the surface which was then scraped away. Still later development progressed in the opposite direction, in which a mixture of steam and air is heated by the combustion of liquid fuel within the hood ⁵⁹², whereby the bituminous surface becomes softened without destruction. It can then be smoothed or receive precoated chippings, or be entirely removed.

A carpet may in time become so worn that noise and vibration become a nuisance to the neighbourhood and a discomfort to travel.

One way of remedying this is by a preliminary heating with a machine of the type that has just been described, followed by a planing off of the old surface, so that a new carpet can be laid on it of uniform thickness. This planing is carried out by a ' Nimpactor,' a machine carrying cutting blades which follows behind the heater ⁶⁰⁴ (Fig. V.25).

Several types of mechanical tampers are in use. One machine delivers 200 to 500 blows a minute of which the strike and weight are controllable ; and is worked by means of a 1½ B.H.P. petrol motor.

In the case of asphalt, an important change in patching technique is desirable. The patch is often left ' proud ' of the surrounding

level, in the anticipation that traffic will further compress it. This frequently does not happen to the anticipated degree. In the meantime, vehicles have bumped twice in passing over the raised area—on coming on to it and on leaving it—shock is given to the roadway, and even if the foundation is not affected the surface is damaged and the unevenness extends.



By the courtesy of Messrs. Johnston Bros., Ltd.

FIG. V.25.—Machine for removing Irregularities from the Road Surface.

Bituminous Surface Improvement.

A successful method of improving a worn macadam (water-bound or tar) or asphalt road surfacing, was introduced into this country by a New Zealander ³⁸⁷. It is something between surface construction and surface dressing, and consists in spreading over the irregular surface, previously primed with a suitable light oil, a mix of fine

mineral aggregate with about 3·5 per cent. of a bituminous cement, such as a cut-back bitumen, and smoothing the layer by means of a blader or planer. This is consolidated by means of passing traffic, and after a sufficient length of time, the grader is again used to preserve the shape of the surfacing. Alternations of traffic and grader are continued till consolidation is effected. Stability was claimed to result from the high internal friction of the relatively fine aggregate and the thin film of bituminous cement. A very even and non-skid surface results at a relatively low cost.

Although different in manipulation and object, this mixture can be compared with Dammann asphalt, in that each depends fundamentally on small aggregate and low percentage of binding material for its stability. Thus, the phenomenon of surface tension is being used in a purer form than in other types of bituminous surfacing.

CONCRETE ROADS

Hydraulic cements and mortar have been known from the days of the Romans ; but the first attempt to investigate experimentally the phenomenon of setting was made in 1756 by John Smeaton, of Eddystone Lighthouse fame. From that time onwards, increasing attention was paid to the problem. Vicat, whose name is immortalized by the testing needle that is used every day, approached a step farther, in 1818, towards the present-day material. It may have been Smeaton's aim "to make a cement that would equal the best merchantable Portland stone" that suggested the name of 'Portland Cement' to John Aspdin, bricklayer, of Leeds, as it appears in his Patent No. 5022 of 1824 ; but though this name is used here for the first time, the material covered by it is not that of to-day.

Modern Portland Cement dates from the work of I. C. Johnstone, in the employ of Messrs. J. B. White & Sons, which led to its being marketed with confidence in 1845. Development was further facilitated by the invention of the rotary kiln by Thomas Russell Crampton, described in Patent No. 2438 of 1877. The final advance in modern invention was the discovery of the rapid-hardening *aluminous cement* by Bied, in France, in 1908, which was marketed in Great Britain in 1923 ; and by the almost immediately subsequent appearance of 'Ferrocrete' in competition with it.

To-day the vast cement interests in all countries have built up an organization which stimulates and directs research on a large scale ²⁴⁴.

The *first modern concrete road* to be laid in this country appears to be St. Mark's Road, Chester, of 1912 ; and Mr. A. Harrison, late Borough Engineer and Surveyor of Southwark, from 1917 onwards,

was one of the first to recognize that concrete was a serious and valuable form of road construction.

The *length of life* of concrete roads, that is to say, the time elapsing until troubles have so far developed that they must be relegated to act as a foundation to other types of surfacings, is impossible to estimate with any degree of certainty, as this depends upon the weight, volume and character of traffic ; and, above all, care in construction. A well-made concrete road, under reasonable traffic conditions, should require little or no attention for many years : but initial trouble may begin after 5 years.

Perhaps the oldest concrete roads still in use (which more accurately should be called 'grouted' roads) are those in Edinburgh, which were laid in 1873. One of them was given an asphalt carpet just before the War, but the others are still as they were when originally made except for some cracks and some repairs.

It is significant that 2 years previously a Patent, No. 889 of 1871, was granted to David Crawford Proudfoot, of Edinburgh, Road Surveyor, for his method of construction and the mixer for the grout. His road consisted of a layer of fine concrete laid on the excavated and rolled ground, on which was spread broken stone, 4 in. or more thick ; this was moistened and grouted with a mixture of water, cement, sharp sand or fine gravel (with or without certain other admixtures). A roller of preferably not less than 15 tons was required.

A variant of this was a layer of 'causeway stones' taking the place of the initial fine concrete layer on the ground.

Periodical surface dressing with suitable bituminous material will often prolong the life indefinitely, but unfortunately very few materials are suitable for securing satisfactory adhesion of the concrete and the holding down grit of a suitable gauge. A measure of success has been obtained by first coating the surface with creosote.

It cannot be emphasized too strongly that the length of life of a concrete depends not only on suitable materials of good quality properly used, but on careful, conscientious, and skilled labour. Too often a concrete road fails on account of unintelligent and slipshod work on the job ; and the sooner that high-class technical control is exercised over all details of mixing and laying and finishing, the sooner will the public be getting proper value for its expenditure of money.

This situation is improved by the use of big machines for large-scale work ; but improvement is often obviously necessary on small jobs.

It has been suggested that the life of a concrete road may be expected to be longer on a soft (but immovable) subsoil than on a hard and rocky one, owing to the capacity of the former to absorb vibrations and shock, and not to act as a resisting anvil aiding in the

fracture of the material between it and the hammer. Also, that liability to fracture from shock is lessened by the inertia of a thick mass of material.

Materials.

The crucial component is the *cement*; its composition, fineness of grinding, rate of hydration and recrystallization, and drying, all effect the strength of the concrete that is made with it through its binding effect, not through its hardness.

There are several well-known types of **cement**, of which the following analyses are characteristic :

	Ordinary Portland Cement.	From Blue Lias.	Rapid- Hardening Portland Cement.	Aluminous Rapid- Hardening Cement.	
Silica, SiO_2	21.96	24.20	20.79	7.52	7.8
Insol. matter	—	0.18	—	—	0.80
Aluminium oxide, Al_2O_3 .	6.48	4.16	5.64	40.22	36.23
Ferric oxide, Fe_2O_3 . .	3.02	2.10	2.75	11.28	2.34
Ferrous oxide, FeO , and Iron, Fe , as FeO . . .	—	—	—	—	5.83
Calcium oxide, CaO . . .	62.96	65.70	64.96	39.87	41.97
Titanium oxide, TiO_2 . .	—	1.25	—	—	3.92
Magnesium oxide, MgO .	1.12	1.21	1.06	0.82	0.47
Sulphur trioxide, SO_3 . .	1.78	—	2.22	—	0.22
Sulphur, as sulphide . . .	—	—	—	—	0.4
Carbon dioxide, CO_2 and combined water, H_2O .	—	0.66	—	—	0.36
Alkali and loss on ignition	1.48*	0.56*	1.56	—	
Other constituents	1.20	—	1.02	0.29	—
	100.00	100.02	100.00	100.00	100.34

Another series of determinations ⁴⁸⁷ is :

	Portland Cements. All Types.	High-alumina Cement.	Granulated Blast- furnace Slag for Slag- containing Cements.
CaO	60-76	36-45	38-50
MgO	0.5-5.5	0.1-1.5	1.7
SiO_2	17-25	4-10	28-38
Al_2O_3	3-8	35-44	8-24
Fe_2O_3	0.5-6.0	1-14	} 0.1-2.0 (as FeO)
FeO	Trace	0-10	
TiO_2	0.1-0.4	1.5-2.5	0.1-1.0
$\text{Na}_2\text{O} + \text{K}_2\text{O}$	0.4-1.3	0.1-0.6	1-2
SO_3	1.0-3.0	0.01-1	0-0.5
S	—	—	0.5-2.0

The difference between ordinary Portland cement and rapid-hardening cement of the 'Ferrocrete' type, is that the latter is of a more refined manufacture and is extremely finely ground. The speed of hardening is such that it attains the same strength in 7 days that the ordinary quality reaches in 28; and that at the end of 28 days 'Ferrocrete' is 50 per cent. stronger. It is claimed that a 6 : 3 : 1 concrete made with 'Ferrocrete' is as strong as a 4 : 2 : 1 mixture made with ordinary Portland cement concrete after 28 days. It is doubtful whether the ultimate strength is substantially greater.

Composition varies somewhat, and in ordinary and blast furnace Portland cements the $\text{CaO}/\text{SiO}_2 + \text{Al}_2\text{O}_3$ ratio is kept between 2 and 3; in aluminous cement the ratio $\text{Al}_2\text{O}_3/\text{CaO}$ can vary between 0.85 and 1.3 without altering the character of the material. Portland cement is controlled by B.S. 12 : 1940 (Amendment 1942). The Portland Blast Furnace Cement, of which the proportion of slag must not exceed 65 per cent., is controlled by B.S. 146 : 1941. The manufacture and composition of the normal material and the rapid-hardening variety have been closely described ⁴³.

The urgency of war conditions has produced '417 Concrete,' which sets quickly and hardens very rapidly. It is specially suitable for use in cold weather. It acts on the principle of the rapid formation of heat, which is then maintained so that the cement should behave as though the temperature were about 60° F. The severe conditions worked to require unusual details of working, such as the heating of the gauging water and of the aggregate, and even the heating of the newly-laid concrete mixture.

The grinding of ciment fondu is such that 8 per cent. is retained by a standard 170-mesh sieve, which is much coarser than rapid-hardening Portland cement. The various strengths of these cements are given in the Table.

COMPRESSION STRENGTHS; 6-IN. CUBES OF 4 : 2 : 1 MIXTURE OF CEMENT WITH FIRST-CLASS BALLAST AND SAND

	24 hours.		7 days.		28 days.	
	Lb./ sq. in.	Kg./ sq. cm.	Lb./ sq. in.	Kg./ sq. cm.	Lb./ sq. in.	Kg./ sq. cm.
Ordinary Portland Cement . . .	1,400	98	4,475	315	5,775	408
Rapid-hardening Portland Cement	2,780	195	5,950	420	7,240	510
Aluminous Cement	9,240	650	10,733	756	11,417	800
Coloured Portland Cement . .	2,350	165	5,450	384	6,500	459

The *setting* of the cement is an intricate chemical and colloidal phenomenon, the rate of which, other things being equal, depends on the fineness of grinding of the material. Ordinary Portland cement is ground to the fineness that 6 per cent. is retained on a 180-mesh sieve, whilst the rapid-hardening variety gives only about 0.5 per cent.

The *action of water* during the setting and hardening of cement is fundamental in importance and complicated in action. Stated in general terms : when a hydraulic cement is finely powdered and mixed with water, a sudden increase in viscosity occurs, which is accompanied by generation of heat, after an interval of time depending on the nature and fineness of grinding of the cement. This indicates the beginning of setting, of which the end is considered to coincide with the rather indefinite end of deformability. From then onwards hardening takes place.

Within this general statement lies such a complexity of *chemical and physical changes*—true chemical reaction combined with and partially dependent upon colloidal phenomena—that careful research during many years has not completely elucidated the problem. It is clear, however, that the fundamental chemical difference between the two types of cement is that Portland cement and its variants liberate lime on the addition of water, and aluminous cement liberates alumina. Probably the clearest ideas so far, that may temporarily be adopted until complete comprehension is reached, are the following :

Portland cement ²⁶³ consists principally of $3\text{CaO} \cdot \text{SiO}_2$ with some $3\text{CaO} \cdot \text{Al}_2\text{O}_3$; or may be of tricalcium silicate + dicalcium aluminate (Alite) and dicalcium ferrite + dicalcium aluminate (Celite) ²⁹⁷. The first action of water is to precipitate amorphous hydrated calcium aluminate, with or without amorphous aluminium hydroxide, together with calcium sulpho-aluminate (which includes some calcium sulphate) and calcium hydroxide. Importance has been attached to the relation between the colloidal and crystalline condition of this hydrated lime ²⁶⁶.

Then, between 24 hours and 7 days, the $3\text{CaO} \cdot \text{SiO}_2$ reacts, forming hydrated amorphous $\text{CaO} \cdot \text{SiO}_2$, and crystallized $\text{Ca}(\text{OH})_2$; some silica is probably liberated at this stage. During the same time, the precipitated amorphous aluminate crystallizes and $2\text{CaO} \cdot \text{SiO}_2$ that is present begins to hydrate, but is the least active in the change. The onset of hardening is due to the hydration of the free lime and the aluminates. The oxides of iron present act as inert constituents.

Another view has led to different conclusions as to the course of the changes, based partly on a highly developed method of microscopic examination. The hydrolysis of calcium silicates is complete, and is unaffected by the quantity of the water in the mix. The properties of the products of hydration are quite different according to the

quantity of water present : a normal quantity of water leads to a high viscosity ; but an excess leads to the formation of crystals (needles) of calcium hydroxide which are absent in mortars of normal consistency. Hydrated silicates of calcium are not formed during the hardening of cement, either crystalline or amorphous. Calcium hydroxide formed by hydrolysis is crystalline and of the shape of the irregular spaces into which it has to fit ; hexagonal plates and rods are formed in the presence of excess of water. Lime expansion is caused by the crystallization of amorphous calcium hydroxide, which only occurs in the presence of a 'promotor,' such as gypsum.

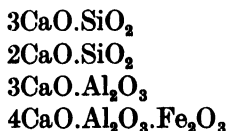
"The hardening of Portland cement depends on the ideal co-operation of colloidal silica and crystallized calcium hydroxide, the latter being the most plentiful and most important ingredient of hardened Portland cement and is thus the cause of hardening."

The results of chemical investigation have been substantiated and extended by X-ray analysis ²⁶⁷, which shows that $2\text{CaO}.\text{SiO}_2$, reacts chemically with CaO to form $3\text{CaO}.\text{SiO}_2$, and that a solid solution is not formed ; that $8\text{CaO}.\text{Al}_2\text{O}_3.2\text{SiO}_2$ does not exist, though this had already been doubted ²⁶⁸ ; that solid solutions are not formed between silicates and aluminates ; that free lime does not reach the proportion of 2.5 per cent. in sound cement ²⁶⁴, and is absent in well-burnt clinker ²⁶⁷ ; and that the following substances have been identified— $3\text{CaO}.\text{Al}_2\text{O}_3$: $4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$; and MgO .

More recent work ⁴⁸⁷, mainly in America, Britain, and Sweden, has led to some modification and extension of these views. The fact that certain compounds can be prepared from the oxides known to exist in cement is no proof that these compounds are actually present in it.

These substances can be considered, with better accuracy, in the broader aspects of 'system.' The most important of these are two ternary systems : $\text{CaO}.\text{Al}_2\text{O}_3.\text{SiO}_2$ and $\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$; and the quarternary system : $\text{CaO}.\text{SiO}_2.5\text{CaO}.3\text{Al}_2\text{O}_3.4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$.

These lead, probably, to the crystalline substances :



together with MgO and some free CaO , according to chemical circumstances. This has been confirmed by Mrs. Lonsdale, F.R.S., in a lecture on X-Rays to the Royal Institution in December 1946.

Potassium, present originally as K_2SO_4 , may appear as a solid solution of the composition $\text{K}_2\text{O}.23\text{CaO}.12\text{SiO}_2$; and the sodium as

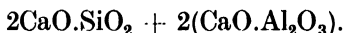
$8\text{CaO} \cdot \text{Na}_2\text{O} \cdot 3\text{Al}_2\text{O}_3$, but this is not certain. This capacity of the main constituents of cement to take up other oxides in solid solution is limited to a few per cent.

The rate at which these various changes take place depends primarily on hydrolysis and hydration, which is controlled by the velocity of penetration of the water through the film of colloidal material that surrounds the reacting particles. Measurements have shown that particles of cement larger than $\frac{1}{10}$ mm. are inert, being so large that colloidal activities are too slow to be of significance. The more the subject is investigated the more are the conceptions founded on pure chemistry becoming modified by colloidal theories, until the latter tend to dominate ²⁹⁷.

Fineness of grinding, therefore, accelerates reaction and thereby hardening, until the particles become so fine that the amount of water required leads to the formation of a weak material.

High Alumina Cement. The peculiar properties of aluminous cement, represented mainly by the 'Ciment fondu' of French origin ²⁶⁴, gave a considerable shock to the industry on its first appearance. It is slow setting, lasting between 2 and 6 hours (according to conditions), followed by rapid hardening. It is claimed to be much more resistant to chemical attack than is Portland cement, provided that the proportion of cement to aggregate is not below a certain amount. (See also ⁴⁰².) It is controlled by B.S. 915 : 1940. "The constitution of high alumina cement is much less completely known than that of Portland cement, and because of the presence of both ferrous and ferric iron compounds and the formation of solid solutions, it is more complicated. The five major components of this cement are CaO , Al_2O_3 , Fe_2O_3 and FeO ; the principal minor components are TiO_2 and MgO " ⁴⁸⁷.

These cements consists mainly of $\text{CaO} \cdot \text{Al}_2\text{O}_3$ or of



The material dissolves relatively easily and becomes hydrolysed into hydrated dicalcium aluminate and $\text{Al}(\text{OH})_3$ and $\text{Ca}(\text{OH})_2$ ²⁶⁹. Both of these separate as colloids, and very slowly. Some $\text{CaO} \cdot \text{SiO}_2$ is also formed. The hydrated lime combines with the calcium aluminate to form $2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 7 \cdot 5\text{H}_2\text{O}$. When silica or $\text{CaO} \cdot \text{SiO}_2$ are low in proportion the action proceeds slowly and is followed by



This is the main cause of hardening.

Subsequently, any hydrated dicalcium aluminate remaining in solution gives up 1 mol. $\text{Al}(\text{OH})_3$ and becomes hydrated $3\text{CaO} \cdot \text{Al}_2\text{O}_3$, and this decomposes into $\text{Ca}(\text{OH})_2$ and $\text{Al}(\text{OH})_3$. As $2\text{CaO} \cdot \text{Al}_2\text{O}_3 \cdot 7 \cdot 5\text{H}_2\text{O}$

is sparingly soluble in water, the last two reactions have little effect on the hardening ²⁷⁰.

Another view ²⁶⁹ is that part of the $2\text{CaO}.\text{Al}_2\text{O}_3$ gradually crystallizes into spherulites; this and the other silicates hydrate on the surface forming an envelope of calcium hydrosilicate which retards solution, but hydration continues slowly by osmosis through the enclosing gel.

The compounds that have actually been identified are: $\text{CaO}.\text{Al}_2\text{O}_3$; $\beta\text{-}5\text{CaO}.\text{Al}_2\text{O}_3$; $3\text{CaO}.\text{Al}_2\text{O}_3$; $2\text{CaO}.\text{SiO}_2.\text{Al}_2\text{O}_3$ (Gehlenite); $\beta\text{-}2\text{CaO}.\text{SiO}_2$; $4\text{CaO}.\text{Al}_2\text{O}_3.\text{Fe}_2\text{O}_3$; iron oxides—ferrous, ferric, and magnetic; and some titanium oxide.

The silicates and aluminates have very different rates of hydration; some are very fast and others slow, but the total effect is that of slow setting. The main reaction responsible for setting and hardening is probably the formation of hydrated di- and tri-calcium aluminate, with liberation of colloidal alumina. The oxides of iron, probably in the form of dicalcium ferrite ²⁷¹, appear to act as restrainers of reaction. It has been observed ²⁷² that, when iron is present largely in the ferric condition, $\text{CaO}.\text{Al}_2\text{O}_3$ is also present; and when mainly in the ferrous state, the unstable $5\text{CaO}.\text{Al}_2\text{O}_3$ is to be found, which probably affects the strength of the cement adversely.

The examination of the *action of water* on the set Portland cement shows that lime is continuously leached out, rapidly at first and then more slowly ²⁸⁷. It is tempting to suggest that the initial rapid solution is of the free lime, and the slow indefinite action involves preliminary hydrolysis of the silicates and aluminates.

The chemical reactions occurring during the setting and hardening of cement give rise to the *formation of heat* that may have a subtle influence that favours cracking, and a direct one on the water required for curing at various seasons of the year.

Portland cement gives out 64–75 cal./g. in 3 days, the period of its greatest activity, and 92–102 cal./g. in 6 months ²⁹⁶. Aluminous cement generates its heat so vigorously that cases have been known when concrete made with it has blown up from the generation of steam. The quantity of heat is about 73 cal./g. ²⁸⁵. It is this property which makes this type of cement so valuable in cold weather.

The interior of a thick mass may rise to 70°, driving water to the surface and weakening the interior through lack of it.

Coloured concrete is produced by the use of *coloured Portland cement*, or by the separate addition of colour. The effect is controlled or enhanced by the hue of the aggregate that is chosen.

Such concrete is used for estate roads where aesthetics are studied, and for traffic lines and lanes, cycle tracks and footpaths, pedestrian

crossings which may be laid *in situ* or with precast blocks, and for kerbs in contrasting colours.

At first glance it is to be expected that any such addition would interfere with the interlacing of the matted silicate crystals and the colloidal hydroxides, and so lessen the strength of the resulting concrete. This is answered by the following figures ²⁸⁰ for the average breaking strain after 7 days for mixtures specially designed to avoid any such weakening :

Colour.	Neat Cement, lb./sq. in.	Neat Cement with 10% of Colour, lb./sq. in.
Black	615	620
Blue	625	630
Brown	605	625
Grass Green	620	625
Marigold	610	630
Red, Brick	605	615
Red, Deep	645	660
Red, Tile	605	615
White	677	687½
Yellow	620	625

Results are also available of tests carried out by the Portland Cement Association ²⁸⁹ on admixtures to a 3 : 1 sand-cement mixture of 7 days :

Red Oxide	Greater increased strength in ordinary Portland cement than in a rapid-hardening type.
Blue : Ultramarine blue	} Increase strength of rapid-hardening cement.
Green : chromium oxide	
Yellow : Yellow ochre	} Increased compression in ordinary Portland cement.
Black : manganese oxide	
Carbon black	Lowers strength.

Other materials used are : barium chromate (yellow), burned umber or brown oxide of iron (brown), Prussian blue, red oxide of iron, crimson lake on an alumina base, manganese black, black oxide of iron or copper and red oxide of iron (chocolate).

A 10 per cent. admixture of a strong pigment gives safer results than a 5 or 15 per cent. of a weaker colour.

The colours most suitable for roads are buff, red, and dark grey. Care must be taken to ensure that the colours are permanent ; a pigment found to remain unchanged in ordinary circumstances may be remarkably unstable in contact with cement, and certain adulterations may be disastrous. (See also ⁵³⁸.)

B.S. 1014 : 1942 has standardized chromium oxide and hydroxides,

red oxide of iron, carbonaceous and iron black, and yellow and brown oxide and hydroxide of iron; no blue pigment is included. The cement is not attacked by slight acidity or alkalinity as the cement itself is alkaline. It must be noted that certain impurities in the pigment, such as traces of lead and zinc, and organic matter, and calcium sulphate, may affect the setting of the cement.

In many cases the choice of *aggregate* for load-carrying concrete is influenced to a greater degree by local conditions than by the necessity of resistance to attrition. Satisfactory materials have been standardized in B.S. 882 : 1944.

In the London area, for instance, large quantities of ballast dredged from the river (Thames Ballast) are available. This material is usually clean and consists of sharp coarse sand and flints, the proportions of which vary considerably from time to time. It makes excellent concrete, but requires careful watching. Variations in character can be roughly corrected by removing or adding sand.

Coarse Aggregate, mainly retained in a B.S. $\frac{3}{16}$ -in. sieve, must be hard and of rough surface. Therefore, *granite* and other hard igneous rocks, such as basalt, are in greatest demand, according to their nature and the locality. *Limestone*, except the very hardest, is suspected of leading to slippery roads, as it is in bituminous mixtures, as well as breaking up in frost, though it may be excellent in the lower layer of two-course work. Crushed gravel is also used.

Slag may also be used as coarse aggregate of $\frac{3}{16}$ in. to $1\frac{1}{2}$ in. nominal size. It is governed by B.S. (War Emergency) 1047 : 1942 as regards its particular characteristics; but in general the material must comply with B.S. 882 : 1940. It must be hard, dense, and of stony texture, stable as regards sulphur, iron, and lime which may cause 'unsoundness'; and with a water-absorption of not exceeding 10 per cent. Chemical and microscopic tests are required.

Foamed blast furnace slag, for use in concrete, is controlled by B.S. 877 : 1939. It is prepared by treating molten slag with sufficient water or other substance to produce a cellular mass. It is glassy, or partially or wholly crystalline in nature. The weight per unit volume and the presence of impurities are the main matters for examination.

Clinker Aggregate for Plain Concrete, B.S. 1165 : 1944, deals with composition and soundness. It must be well burnt and fused or sintered, and possess not more than 1 per cent. of soluble sulphate calculated as SO_3 ; its soundness is ascertained by a pat test. The specification does not control fineness or grading, but it is customary to require that the surface of the coarse aggregate must be free from adhering fine material, as this may lower the strength of the concrete by as much as 40 per cent.

The following grading of the coarse aggregate is typical of that usually adopted :

Depth of Slab, inches.	Size of Mesh passing all Material, inches.	Maximum Length of Stone allowable, inches.
CRUSHED AGGREGATES		
6	$\frac{3}{4}$	1
7	1	$1\frac{1}{2}$
8 }	$1\frac{1}{2}$	2
9 }		
10 }		
UNCRUSHED AGGREGATES		
6	1	2
7	$1\frac{1}{2}$	2
8 }	2	3
9 }		
10 }		

Passing $2\frac{3}{4}$ in. screen	. . . . .	100
$2\frac{1}{2}$ "	. . . . .	95-100
$1\frac{1}{2}$ "	. . . . .	30-65
$\frac{3}{4}$ "	. . . . .	0-15
$\frac{3}{8}$ "	. . . . .	0-8

Fine Aggregate. This is required to fill the voids within the coarse aggregate, and should pass a B.S. $3\frac{3}{16}$ in. mesh sieve. It may be obtained from a crusher, pit, or seashore. The requirements as to quality are much the same as for asphalt construction, and may be tested as a 3 : 1 sand-cement briquette. The finest material in the sand should be removed, as it tends to form a scum on the surface of the concrete and to carry away cement with it.

The grading of the total aggregate is shown in the Diagram on p. 198 and it should approximate to :

Passing $\frac{1}{2}$ in., retained $\frac{3}{4}$ in.	. . . . .	%
$\frac{3}{4}$ "	. . . . .	25
$\frac{3}{8}$ "	. . . . .	40
$\frac{1}{8}$ "	. . . . .	35
		100

and have a fineness modulus of about 5.6.

Moist sand occupies a considerably bigger volume than dry sand, 2-5 per cent. by wt. increases the volume by 15 to even 40 per cent. ; and if no allowance is made for this, incorrect proportioning will result. Above 5 or 6 per cent. moisture, this effect gradually diminishes till the sand is inundated, when the volume is the same as that of the completely dry sand (see *Tests*). The excess bulk of the partially

wetted sand results from the balance of the sand-water-air intersurface tensions, and these forces are thus seen to be considerable for them to hold a mass of sand inflated to such a degree.

Considered as a whole, the limits of the grading of aggregate for concrete have been summarized in Fig. V.26.

Zone A : Suitable for mixes of high workability, low cement content or with coarse aggregates containing much material of small size (passing $\frac{3}{8}$ in.).

Zone B : Suitable for most purposes. (This zone is identical with that given in B.S.S. 882 : 1944 for 'medium' sands.)

Zone C : Suitable for mixes of low workability or with coarse aggregates of large size.

The extreme limits of grading allowed by B.S.S. 882 are also shown on the diagram.

The grading of the coarse aggregate has not been found to be of very great importance, but best results are nearly always obtained when there is a considerable proportion of particles of or near the maximum size. The grading for $1\frac{1}{2}$ -in. gravel normally used here is shown on the diagram, but almost any grading within the limits allowed by B.S.S. 882 gives good results.

An important deduction from the grading of the aggregate that has been developed by the cement industry is that of the *fineness modulus*.

This is obtained by sieving with standard sieves (100, 50, 30, 16, 8, 4, $\frac{3}{8}$ in., $\frac{3}{4}$ in., $\frac{1}{2}$ in.), and successively summing the percentages of the material retained by each sieve, and dividing the total by 100. Its usefulness lies in the indication obtained of the water required (and indirectly, the amount of cement) for a given consistency, because different mixtures having the same fineness modulus require the same amount of water ²⁶².

Water should be fresh and clean, and preferably free from salts, as these may interfere with the course of setting and hardening; in the case of sea water, they may cause corrosion of the reinforcement and retardation of setting and hardening, and (of less importance) efflorescence on the surface of the concrete. Contrary opinions are met with concerning the use of peaty waters.

Desirable *proportions* of stone, sand, and cement vary for different requirements.

A 2 : 1 : 1 mixture for reinforced concrete is preferred by some to the more usual 4 : 2 : 1, as the strength of this mixture is less affected by a change of water content than the other—in a quoted case by 10 per cent. instead of 20 per cent. Another mixture that is employed is the 5 : 3 : 1; but 95 per cent. of the mixtures generally used are 4 : 2 : 1.

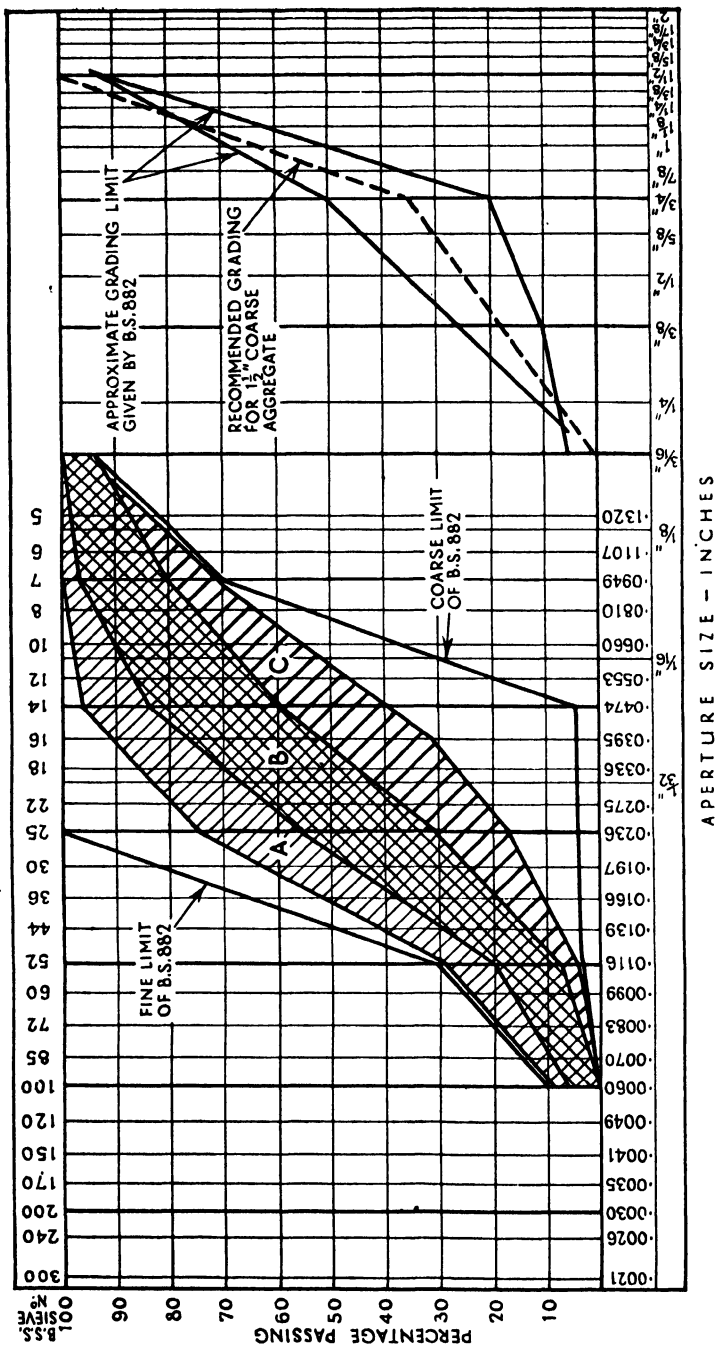


Fig. V.26.—Limits of Grading of Concrete Aggregate.

For very heavy traffic a 5 : 3 : 1 mixture may be used for a lower course and a 3 : $1\frac{1}{2}$: 1 mixture on top. A modification of this contains $\frac{3}{4}$ – $\frac{3}{8}$ -in. granite chippings, the final mixture being 3 (2 in. granite + $1\frac{1}{2}$ – $\frac{1}{4}$ -in. granite) stone : 0.75 sand : 1 cement ; this has been found to give a dense and durable wearing mixture ²⁴⁶.

A very fine sand requires more cement than a better-graded one. This may be on account of the higher proportion of voids in an ungraded sand, or because, as is obvious from surface considerations, more cement must be required to coat a given weight of finely divided matter than the same weight of coarser material. (See *Colloids*.)

The amount of water added to the mineral matter must take into account the quantity already present in the sand and in the stone. Sand usually contains 2–5 per cent., which may increase its volume by 15–40 per cent. ; the coarse aggregate may contain 2 per cent. without change in bulk. About 1 per cent. of water may be absorbed. An excess produces excessive contraction, a weak concrete, with a porous surface due to the formation of laitance which powders away. The correct quantity for use with Portland cement must be determined by preliminary trial and its slump test taken ; with aluminous cements the slump test does not work. The proportions must then be rigidly adhered to.

In construction, Portland cement requires about 5–6 gals. of water per cwt. of cement ; the aluminous type needs not more than $4\frac{1}{2}$ gals. in spite of its rise in temperature, but precautions against escape are necessary.

It must be noted that all the constituents concerned with the setting and hardening of hydraulic cements are soluble in pure water, but are substantially insoluble in water of ordinary drinking quality.

Many **admixtures** have been suggested for the improvement of the concrete by promoting the rapidity of set and hardening, resistance to the entry of water, workability of the mixture, and resistance to wear. The summary of these materials ²⁴⁵ and their result on the Portland cement concrete produced appears on page 200.

In general, salts of metals of low atomic weight exert a favourable influence on the strength of cement, whilst those of high atomic weight are injurious ²⁹⁷.

Admixtures to aluminous cements have been found to be very active ; a very small addition of *lime* causes rapid setting, which becomes almost instantaneous with 10 per cent.

Portland cement is usually said to cause rapid setting of aluminous cements due to the formation of $4\text{CaO}.\text{Al}_2\text{O}_3$; but it has been found to be possible to produce a series of mixtures graduating from flash setting and slow hardening to slow setting and rapid hardening ²⁷⁴. The

strength, however, is said always to be less than that of the pure aluminous cement, and that the hardening is often capricious.

Sodium carbonate also diminishes strength.

The incidental admixture of *atmospheric carbon dioxide* has a hardening effect by converting the free lime into calcium carbonate.

Specially treated *cast-iron granules*, mixed with cement and a little sand, are claimed to give a very hard-wearing concrete. These granules have passed through 6 sieves, and are recombined to give

Material.	Proportion and Mix.	Result.
Calcium chloride .	2-4% wt. of concrete	Increased strength; possible discoloration. Setting and hardening accelerated; no diminution of strength; surface good ²⁸³ .
Calcium chloride and Sodium chloride	Suitable concentration in mixing water	Protects against some degree of frost during early setting and hardening. May attack reinforcement. (See also ²⁹⁴ .)
Sodium chloride .	5%	May cause efflorescence. May lower beam strength by 30%.
Calcium hydroxide	Mixed in cement	1-2% loss of strength for each 1% added. Rich mixtures are affected more than lean: 1-9 and 1-6 mixtures, slightly increased workability. 1-5 and 1-4 mixtures, little affected. 1-3 and 1-2 mixtures, slightly decreased workability. In usual concrete mixtures: volume increased by 60% of volume of loose lime added.
Powdered slate .	10% to 90% of cement 4 : 2 : 1 concrete + 2½ slate calc. on cement	Final setting prolonged 30 min. Slightly higher compression values. Best results when finest sand was absent.
Brick powder . .	1% on cement in 4 : 2 : 1 concrete in 28 days	Reduction of strength by %
Clay	Ditto	0.008
Whiting	Ditto	0.22
Sand	Ditto	0.24
Limestone	Ditto	0.37
Lava	Ditto	0.39
Fluorspar	Ditto	0.40
Kaolin	Ditto	0.43
Tufa	Ditto	0.47
Ironite	Ditto	0.51
Yellow ochre . . .	Ditto	0.60
Mica	Ditto	0.68
		1.10

the densest mixture. A mixture of 1 part of granules to $1\frac{1}{4}$ of cement and sand is a rich mixture.

Uses of Cement. Most of the cement used in roadways goes to the formation of concrete, but a growing amount is being used for soil stabilization, by direct mixture.

Concrete Mixture.

The concrete mixture ³⁶⁶ is usually apportioned by volume, but apportioning by weight is gaining in favour. The vague formula as, say, 4 : 2 : 1 is always unsafe, for the important reason that it takes no account of the grading of the two aggregates. Consideration must be given to the amount of water in the sand, of which 5 per cent. may increase the bulk by 30 per cent. and more. Of the various methods for the apportioning of the components of concrete, the best is that based on sieve analysis which gives a knowledge of the voids which leads to a mixture giving a dense material.

Tables and graphs have been devised to indicate the required proportion of cement and fine and coarse aggregates, taking into account the various properties of the components ^{281, 282}.

The lax attitude towards the accurate proportioning of the concrete ingredients for maximum density, as compared with asphalt practice, was probably due to the fact that 1 per cent. more or less of cement does not make an important difference to the strength of the resulting concrete; whereas it might make all the difference between a stable or unstable asphalt surfacing. To-day, the importance of maximum density of concrete is being increasingly recognized.

This requirement is made emphatically clear by the work of Professor H. N. Walsh, of University College, Cork. An elaborate investigation has shown the way to the best mixture for concrete, and to the necessary works control ⁵¹⁷. Minimum voids is a fundamental necessity and, so far as coarse aggregate is concerned, can best be obtained by screening $\frac{1}{8}$ -in. to 2-in. crusher-run material into 8 portions, storing these in separate bins, and remixing them in the desired proportions. A vast amount of research has been done on proportion and curing, but there is still room for greater attention to workmanship on the road.

The control of the *water-cement ratio* is of outstanding importance as it determines the strength of the concrete, i.e. of the hydrated cement, other things being equal. A ratio of 1 signifies 11.2 gals. water to 1 cwt. Portland cement; so that a ratio of, say, 0.45 represents a quantity of water of approximately 5 gals. Any such quantity would have to be modified by the amount of moisture already in the aggregate. For aluminous cement, the proportions are $6\frac{1}{2}$ gals. per

1 cwt. With every mix there is a water-cement ratio which will render possible the maximum strength. (See Table ³⁹⁸ below.) Ciment fondu requires 40 per cent. by wt. of water for complete hydration ; and 55 per cent. in the ideal water-cement ratio.

Abram has expressed his theory by the equation :

$$S = \frac{A}{B^x},$$

where S represents compression strength after 28 days ;

A and B ,, constants ;

x ,, water-cement ratio by volume.

In this country A = 14,000

B = 5

A modification, which takes account of curing at a particular temperature is :

$$S = \frac{200T}{4^x},$$

where S represents probable strength after 28 days ;

T ,, average curing temperature in °F. ;

x ,, water-cement ratio.

There are many minor influences which have considerable effect on the results of these calculations ⁴⁸¹.

(Based on the work of Prof. Abram.)

Mix.			Water required (Gal./cub. ft. Cement.)	
Cement.	Fine Aggregate.	Coarse Aggregate.	Minimum.	Maxim.
1 . . .	1½	2½	6.0	6.6
1 . . .	1½	3	6.6	7.2
1 . . .	2	3	6.9	7.5
1 . . .	2	4	7.2	7.8
1 . . .	2½	5	8.7	9.4
1 . . .	3	6	9.9	10.3

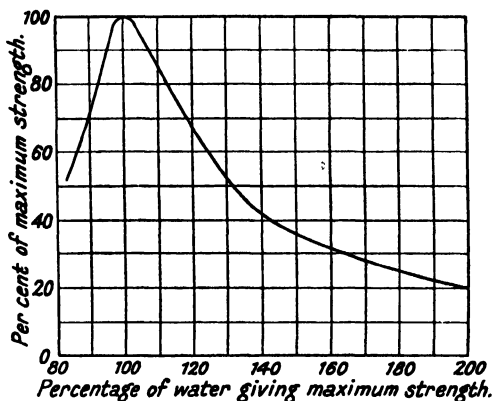
The conversion of cement powder to a rock-like mass depends fundamentally on the chemical reaction of the cement with water, and such a reaction implies definite quantitative proportions of the two materials for a complete chemical of each component ; but practical considerations militate against close adherence to the theoretical proportions.

It is this that underlies the experience that both excess of water and deficiency of water result in a rapid diminution of strength. Sometimes this is brought about by the ideas of ' old Bill ' superseding those

carefully worked out in the laboratory. The former may also render the concrete porous and cause contraction, and the latter prevent effective consolidation ³⁹⁸ (Fig. V.27).

It is safe to assume that there is no deficiency of water when the amount present is sufficient to enable the concrete to flow and consolidate without undue tamping and manipulation. The use of sufficient water only to give reasonable workability is the most economical course, although this will involve a somewhat higher cement content than would be required to produce the same strength under laboratory conditions.

For concrete roads with little or no reinforcement the proportion of water should be such as to render possible thorough consolidation without the necessity of tamping beyond the stage when moisture is beginning to accumulate upon the surface. When, however, closely spaced reinforcement is being used around which the concrete must be thoroughly packed, more water will be necessary, and to maintain the same strength additional cement must be added. In all cases it is better to attain workability by altering the proportion of fine aggregate and coarse aggregate than by adding more water than is required.



By the courtesy of Concrete Publications, Ltd.

FIG. V.27.—Graph showing the Effect of Excess of Water on the Strength of Concrete.

It is found in practice that the water content of aggregate varies considerably. At times there may even be substantial variation in different parts of a heap—the interior may be either drier or wetter than the outside. Aggregate should therefore be tested continually. It must be remembered also, when using porous aggregate, that unless the aggregate is thoroughly soaked before being used, it will absorb water from the mixture; and unless provision is made for this the moisture remaining may not be sufficient for the proper hydration of the cement. A porous foundation may have a similar effect.

A method for regularizing the quantity of water in an aggregate, for the more certain proportioning of the mixture, has been worked out by the Road Research Laboratory ⁵¹⁴. In this, the aggregate is saturated with water and then vibrated, whereby a definite quantity

of water remains in the aggregate, which is sufficiently constant for the resulting concrete to be stronger and more uniform.

The workability of the mixture is measured by the slump test. It is this required workability that reduces the strength of concrete to below that obtainable according to chemical considerations alone, as is seen from the following figures :

Portland Cement Concrete with a Slump Test of		is
1½-1 in.		too stiff, but already below maximum strength
2½ "		65% of the maximum, after 28 days
6-7 "		50 " "
8-10 "		30-40 " "

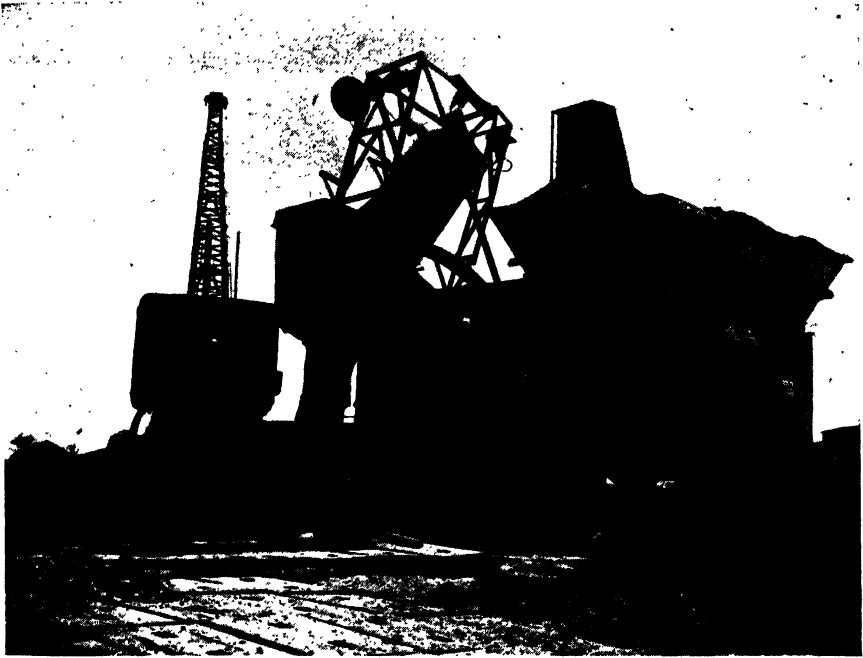
For concrete roads a slump test of 2-4 in. is usual, corresponding to a cement-water ratio of 0.8-1.0 (according to the aggregate); but this should be as low as practicable.

These conventional (one might almost call them ‘ classic ’) ideas on workability have received a shock which has almost obliterated them. The more recently developed vibration methods have enabled ‘ no-slump ’ concrete to be laid satisfactorily—a concrete having only sufficient water to enable chemical and physical reactions to take place, and none in excess to facilitate the handling of the mass.

A further shock has been given to prevailing ideas on the proper nature and grading of aggregate for concrete. Difficulties of supply led to the discovery that concrete for the construction of estate roads can be made from aggregate containing fist-sized flints and an appreciable quantity of clay. (See also ⁶¹².)

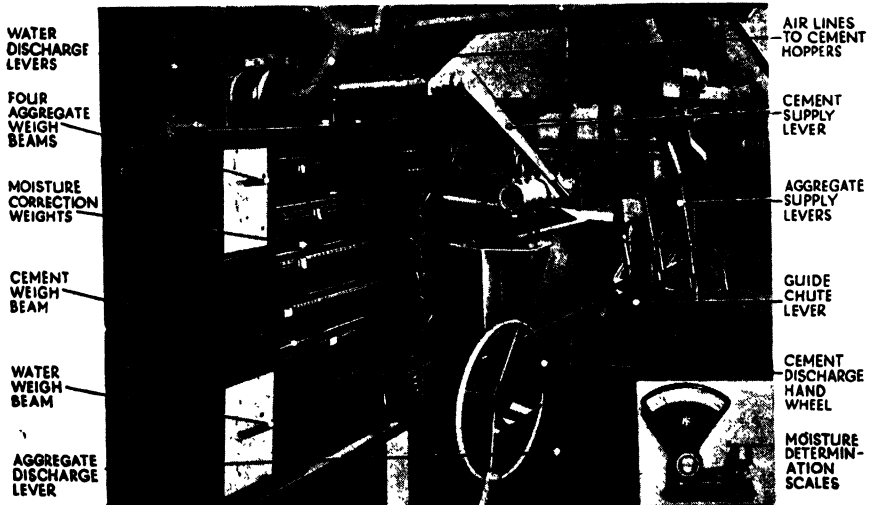
Mixing. The fundamental requirements are the thorough mixing, and continuous accurate control; and this can be attained by mechanical means. An operating platform is shown in Fig. V.29. Both time and speed of mixing are important. It has been found that the strength, density, uniformity of quality, resistance to entry of water, and resistance to mechanical wear of concrete increases rapidly with time of mixing up to 1 minute, with a useful limit of 2 minutes. Wet mixes show less advantage from this extra time than dry, and rich less than lean, coarse less than fine. In any case, the better the mix the easier it is to handle. Air voids are easily got rid of in properly proportioned concrete.

The lowest temperature for mixing with safety is 36° F. on a falling thermometer and 34° F. on a rising thermometer, unless special precautions be taken against the action of frost: such as increasing the



By the courtesy of Blaw-Knox, Ltd.

FIG. V.28.—Mobile Concrete Batch Plant.



By the courtesy of Ransomes & Rapier, Ltd.

FIG. V.29.—Concrete Operating Platform.

amount of cement, whereby the generation of extra amount of chemical heat is made to oppose the attack of cold, the use of warmed water, and of a setting accelerator, such as calcium chloride. During frosty weather care should be taken that the aggregate is thoroughly thawed out before use.

Aluminous cement requires mixing for about three times as long as ordinary Portland cement ; the effect of chemical heat which drives off some of the gauging water must be counteracted.

An example of a batching plant is shown in Fig. V.28.

Construction.

Until the relatively recent development of *soil stabilization* the road engineer felt that he was in great measure helpless regarding the ground in which he built his road. With the study of the chemistry and specially the physics of the soil and the means of improving it, confidence increased so much that to-day the stabilization of the soil has led to the decrease in the thickness of the concrete surfacing.

The concrete road is laid on a *formation* composed of hard material, such as clinker or gravel, which is spread to the proper shape and consolidated with a roller of not more than 5 tons weight. This provides a regular and even bed for the concrete, a means of drainage, and room for some expansion of the subsoil. The addition of a layer of waterproof paper aids the protection of the concrete from water, often impure, rising from below, or gauging water and cement being absorbed downwards.

The actual methods of *laying* need not be described in detail, but mention should be made that expansion of concrete, for which expansion joints are usually essential, is due not only to temperature but also to dampness. They can be summarized as follows :

(a) *Continuous Construction.* This method is the simplest and quickest. It does not make allowance for expansion and contraction resulting from temperature changes of the concrete ; but in situations roughly north of a line drawn east and west through Manchester, and in Wales and Ireland, changes of temperature are neither excessive nor sudden, so that this method of laying without expansion joints is permissible.

Under less-favourable conditions continuous construction in this country may be expected to result in transverse cracks at intervals of 50-60 ft. and in longitudinal cracking where a road exceeds about 20 ft. in width.

(b) *With Expansion Joints.* This is the most usual form of construction in this country. In the above-mentioned areas, where

expansion joints are considered necessary they can be placed 60–100 ft. apart. Where heat changes are more considerable and more rapid this interval should be reduced to 30 ft. for un-reinforced roads, but may be increased to 45–55 ft. where substantial reinforcement is adopted.

These expansion joints may traverse the road from side to side ; or may meet at a central longitudinal joint. Theoretically, the best arrangement of all is the staggered joints equidistant along the central joint, though practice shows that cracks may form as prolongations of the joints from the opposite side.

(c) *Alternate Bays.* This method of laying had early popularity for roads, but has fallen into disuse, owing to inherent defects and the technical advantage of continuous working. The chief benefit that was claimed for this method of construction was that the alternate bays shrink during drying and so that the intermediate ones can be laid with small expansion joints. One of the greatest difficulties of concrete road construction is the maintenance of an even surface in the vicinity of the joints, and this difficulty is accentuated in the case of the alternate bay system.

The bays first laid will be set and partially dried out before the other bays are laid, and in consequence the concrete of the latter is inclined to settle to a slightly lower level. When laid on a gradient there is a tendency for concrete to flow downhill, causing a depression on one side of a joint and a hump on the other. The avoidance of this is a further reason for using as stiff a mix as practicable.

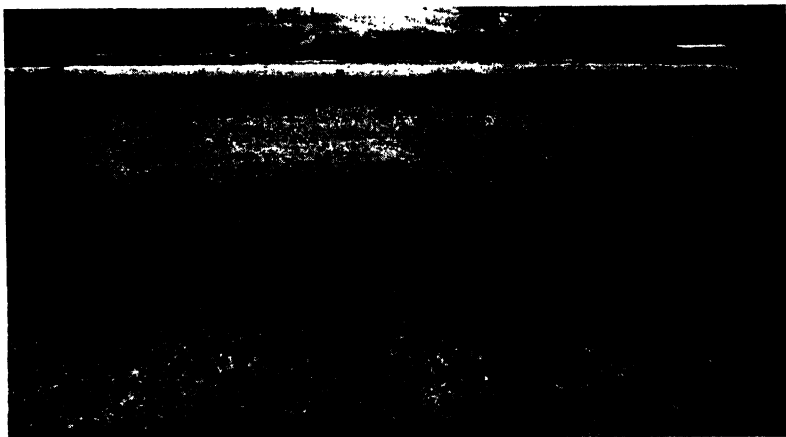
In some cases also the bearing qualities of the sub-soil adjoining the first laid slabs appear to be affected by the weight of those slabs, especially if wet weather intervenes, and to cause subsequent unevenness at the joints. Small slabs are at times inclined to rock, a defect which it is very difficult to cure.

The concrete is sometimes *laid in two layers*, the upper containing very hard stone so as to act as a wearing surface to the lower. This is justified where local stone is not of the best quality and where there is much horse traffic ; and it has been claimed to facilitate subsequent opening of the road. At the same time, it has been condemned as diminishing the full strength of the concrete.

Hand-placed Concrete.

A novel, if expensive, but successful method of concrete surfacing is the 'hand-placed' which, if obsolete, is worthy of description, because of the good service given in exceptional conditions, such as gradients too steep for ordinary construction. (To-day, the same effect is produced by vibrating 2-in. stone into the surface of the 'green'

concrete.) One section was laid on the Old Portsmouth Road, Roehampton, off the Kingston Road (Fig. V.30). The foundation course, 7 in. in thickness, is of 6-1 Thames ballast concrete. The surface of this was left rough and upon it was placed, while it was green, a layer of cement mortar (2 : 1) $1\frac{1}{2}$ in. thick, in which was embedded by hand $2\frac{1}{2}$ -in. gauge, hand-broken Guernsey granite macadam, which had been lightly coated with cement wash. The granite was beaten into the mortar by large flat beaters and brought to a true surface. Surplus mortar was brushed off and the whole given a dressing of P84 Silicate of Soda 14 days after laying, a second dressing 2 days later, and a final dressing 2 days after. Transverse expansion joints were provided at intervals of an average of 40 ft.



By the courtesy of The Cement Marketing Co., Ltd.

FIG. V.30.—Hand-placed Concrete Macadam on Steep Gradient.

By 1946, this road had been carrying a heavy load of traffic of an average of about 12,000 tons a day for the 12 years immediately preceding the war, and it remains in excellent condition nearly 20 years after construction. The cost was somewhat higher than the usual type of construction, but except for a little attention to the joints the cost of maintenance has been negligible. The surface grip is excellent and involuntary cracks few.

In a previous experiment on similar lines the cement-coated granite macadam had been spread by shovel and rolled in, but the more satisfactory surface resulting from hand placing fully justified the extra expense.

Whatever be the methods of laying, it is recommended that the *carriageway be divided* in the following manner :

Width of Carriageway in feet.	Strip.
18	Two 9 ft. wide
20	10
24	12
30	15 or three 10

the advantages being easier and quicker construction, no interference with the traffic and traffic guides resulting from the longitudinal joints.

When laid on a gradient greater than 1 in 18, the surface should be roughened, usually by the use of coarse aggregate.

Vibrated Concrete was beginning to claim attention in 1932 in Germany and America ^{37, 87, 427}, and it is becoming increasingly popular here. The object of vibrating is to produce a much more fully compacted concrete mixture which would have been too stiff to be placed economically by hand. Concrete with a slump test of 1½ in. can be dealt with when a hand-laid mixture would have had to show a test of 5-6 in. For road work a slump test of 1 in. down to nothing is admissible. The limit of stiffness is set by the ability of plant to deal with it. A 1 : 2½ : 5 vibrated concrete would have the same strength as a 1 : 2 : 4 mix compacted by hand.

This much drier concrete mixture results from a lower water-cement ratio ; and the lessening of the water present leads to greater density and strength, resistance to weather, to less shrinkage due to loss of water, and to less tendency to segregation ; and less cement is an economy. If there is any surplus water present this, with advantage, is brought to the surface, but with the disadvantage of losing sand and cement. Over-vibration of a suitable mix produces the same result ; the beginning of the appearance of liquid and the cessation of the escape of bubbles indicates the limits of safety.

The effectiveness of vibration is roughly proportional to the amplitude and to the square of the frequency ^{471, 472, 473}. The amplitude is of less importance than the speed and length of time of vibration ; it is usually about 1/16 in. to ¼ in., and varies with the frequency. More exactly two equations express the relationships :

$$f = A(2\pi n)^2$$

$$e = cAn^{2.4}$$

where f represents acceleration in in./sec. ;

A „ amplitude in inches ;

n „ frequency ;

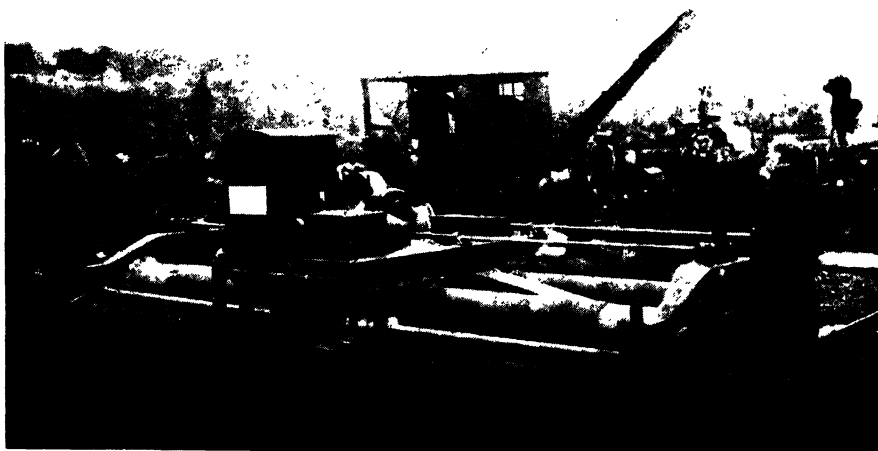
c „ constant, depending on conditions of equipment and testing.

e „ efficiency.

Power is approximately proportional to f^3 .

On a vibrating table the first equation can be fulfilled, but *in situ* it is impossible to establish A or f . Usually, 3,000 v.p.m. are suitable, but for wetter mixes this is increased ^{485, 486}.

America, Germany, Denmark, and Britain have designed machines for laying this dense concrete ; and in surface vibrators there appears to be a tendency toward a relatively narrow vibrating beam, running on rails and actuated by pneumatic or more usually electrical power. In one case ⁷⁷ a petrol engine of 1.3 h.p. sufficed for 3,000 v.p.m. with 6.013 in. amplitude of vibration and acceleration of 5.9g.



By the courtesy of Messrs. Stothert & Pitt, Ltd.

FIG. V.31.—Concrete Levelling and Vibrating Compacting Machine.

The vibrating of concrete has aided in the solution of the problem of laying a non-skid surfacing on a gradient varying between 1 in 12 and 1 in 6.5. The aggregate used consisted of 4 parts washed river ballast and $1\frac{1}{2}$ parts washed river sand. On the concrete mixture 2-in. Guernsey granite was spread 1 stone thick, and a vibrating tamper applied. A thin coat of cement mortar (3 sand to 1 cement) was spread and the whole vibrated to 4 in. thickness. The surface was subsequently brushed to expose the granite ⁵³⁹.

The remarkable technical improvement attained in vibrated concrete has led to its wide adoption. Fig. V.31 shows a levelling and vibrating plant. The roller-like objects are in reality distance pieces,

whereby the track can be varied considerably in width. The vibrator, working at 3,300 per min., is seen in part between them : it is claimed that the flat triangular shape gives an equal degree of vibration along its whole length.

The power required varies from 7 to 14 h.p., and the travelling forward is at a speed of 1-8 ft./min. and 60 in reverse.

Expansion Joints. The material for filling the expansion joints is ever being improved, the ideal being that the jointing shall be capable of withstanding intermittent compression without appreciable reduction in width when pressure is removed, and without being forced out of place ; and of adhering well to the concrete on either side of it, otherwise water will find its way into the road.

Any material which expands after compression might make a good joint filler. Natural cork is said to be capable of expansion, after a 33 per cent. compression, at the speed of contracting concrete. Granulated cork mixed with fluxed high softening-point bitumen can be compressed 50 per cent. without edge displacement with subsequent resumption of normal shape ³⁸⁸. Cork mixed with vulcanized rubber has also been found useful ⁸⁹ ; and vulcanized rubber, highly aerated with an inert gas (probably nitrogen), is used ³¹⁷.

An ingenious joint has been devised of which the upper part consists of a tubular rubber strip so indented, that, when squeezed by the expanding concrete, it is forced downwards and so escapes extrusion ⁴⁸⁰. A mixture of cotton waste and rubber has been tried ³⁰⁰.

An asphaltic mixture, blended so as to be elastic in the cold and unextrudable at higher temperature has been in use for some time ⁴⁷⁴, and is suitable for employment with concrete or between wood blocks and the kerb.

Long spring-like fibres of cane incompletely saturated with a bituminous material (so as to retain a proportion of air bubbles for resilience) is well known, and claims to have solved the problem, especially when sealed with another proprietary material having the advantage of being light coloured like concrete ¹⁴⁵. The material is compressible 50 per cent. and regains 70 per cent. of its original thickness after 1 hour of release. Pre-moulded jointing has been used in America.

The arisses of expansion joints are usually rounded, as sharp edges frequently become broken. Strength across the gaps is maintained by means of dowel bars.

Dummy joints—grooves, 15-18 ft. apart—are sometimes formed along the surface of the concrete, insufficiently deep to weaken it under traffic but sufficient to encourage the formation of cracks along that line rather than anywhere else. (See also ²⁷⁶.)

Tamping requires special care to secure the maximum of density with the minimum formation of laitance. The tamper is at least 7 lb. per ft. length, and should be steel-shod. Its use is followed by the *finishing board*, which eliminates the waves and ripples resulting from tamping. A belt is sometimes employed, but the board is preferable as it helps to preserve the camber.

Curing. Highly important is the effective curing of the concrete by preventing rapid evaporation from its upper surface, whereby the chemical processes of setting and hardening may be harmed. This is often by no means easy to do, and for that reason is liable to be neglected.

Various methods are employed, including spraying and ponding with water, covering with earth, sand, straw or burlap, maintained in a wet condition, and the application of bituminous emulsion; also spraying with calcium chloride which has a hygroscopic effect.

Spraying with water is often the most simple and least expensive form of curing, particularly during damp and cloudy weather, but during periods of high temperature, or drying winds, it is difficult to maintain the surface in a continuous and proper wet condition.

Ponding gives excellent results, but requires an abundant supply of water easily applied. Both spraying and ponding are objectionable during frosty weather. Spraying, however, can be continued after the road has been thrown open to traffic, whereas the road must be closed so long as ponding is in operation.

Covering with earth or sand, to be effective, requires a depth of about 3 in., and even when supplies of suitable material are easily obtainable, is likely to be relatively expensive. Straw is now seldom used as it is expensive and troublesome, particularly during windy weather.

Burlap has been used extensively, and is convenient and inexpensive. A special impervious paper is also available for the same purpose. These materials, however, share with earth, sand, straw, etc., the disadvantage that they must be removed before the road can be opened to traffic. This was not so important when slow-hardening cements were used, and traffic was not allowed over a concrete road for 14 to 21 days, but with the general adoption of rapid-hardening cements, and a shortening of this period to 4 or 5 days, it is desirable that the method of curing should continue to be effective under traffic.

The use of calcium chloride for curing is not very popular, and its effectiveness varies with atmospheric conditions. (See *Effect of Salts*.)

The use of bituminous materials ²⁸³, particularly in the form of emulsions ²⁵³, has been extensively adopted for many years. The emulsion should be applied to the concrete immediately this can be

done without marking the surface, in any case within about 8 hours, at the rate of one gallon to 6 to 7 yards super. Application may be either by squeegee or brush, or, preferably, by pressure spraying machine. A disadvantage is the tendency to raise the temperature of the concrete on a hot sunny day, and so to increase the rate of hardening above its normal speed.

If properly applied, the emulsion effectively seals and insulates the surface of the concrete for a considerable period, and tends to increase substantially the strength of the concrete. It also assists the adhesion of bituminous dressings subsequently applied to the surface.

' Sandwich ' Concrete Roads. The ' Sandwich ' system of concrete road construction has given excellent results, particularly under light traffic. One of the authors laid down an experimental section of this type of construction in place of wood-block paving on an important main road carrying about 25,000 tons per day. The new concrete surface was laid upon the old concrete foundation and remained in very fair condition for about 6 years, costing practically nothing for repairs ; but it is hardly reasonable to expect cheap construction of this kind always to stand up under such severe conditions. No doubt the unyielding concrete foundation was of great assistance, but that this surfacing material gave results so satisfactory in a road which had carried some 50 million tons since it was laid, is a fact of considerable importance.

This type of construction may be laid on well-consolidated or any other substantial foundation, the surface of which is reasonably impervious to prevent the cement from escaping downwards.

Upon the foundation should be evenly spread a layer of 2-in. to 2½-in. macadam, lightly followed by consolidation by rolling. Upon this should be spread cement mortar—2 parts sand to 1 part rapid-hardening cement—mixed fairly stiff and of an even thickness of 1½ in. to 1¾ in. according to the gauge and depth of stone. A top coat of macadam similar to the bottom layer should be applied over the mortar and the whole rolled with an 8- or 10-ton roller until the mortar has permeated both top and bottom layers of stone. As mortar appears above the surface during the process of rolling it should be carefully brushed into the interstices of the stone, and any depressions made up with stone of slightly smaller gauge than that used for the top and bottom layers.

The foregoing would give a finished thickness of about 4 in. to 4½ in. If the total desired thickness exceeds the latter figure the layer of mortar should be increased proportionately. Rapid construction is important, and rolling should cease within 40 minutes or at most 1 hour from the time the mortar is mixed. The finished surface

should be free from traffic for at least 5 days, and in dry weather it should be kept moist during that period.

The opening of the road to *traffic* usually has to be delayed for 3 or 4 weeks according to the time of year; but with rapid-hardening cements this may be reduced to about 4 days, or, with aluminous cement, to 1 and 2 days. These figures for the rapid-hardening cements may have to be prolonged if the temperature is as low as 50° F. and the weather moist.

Concrete, even more than other surfacings, is benefiting as regards suitable components and length of life by the diminution of iron-tyred and shod traffic. The tendency of concrete to break away or fray at

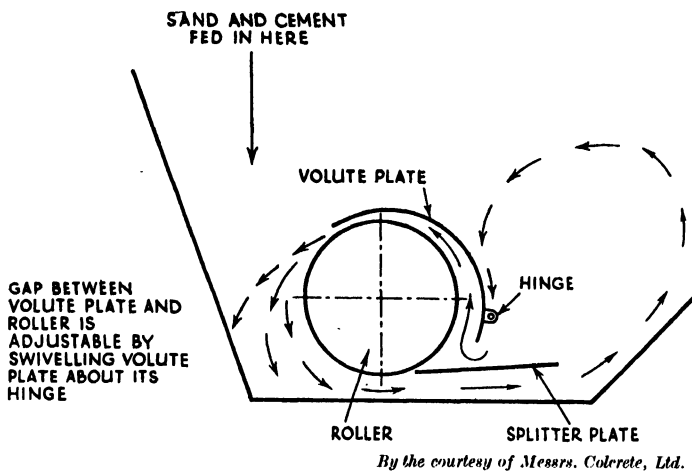


FIG. V.32.—Flow Diagram for the Concrete Roller Type Grout Mixer.

the edges under harsh impact necessitates the adoption of special precautions. In any event, all arrises should be rounded and, where there is any likelihood of iron-tyred traffic, aggregate of the toughest kind should be used at the surface, even though this may involve the adoption of two-course construction.

Great advantages, amongst others the increase in strength of 22 per cent. under laboratory conditions, are claimed for the passage of cement and water through a colloidal mill on its way to admixture with sand to form a *grout* (Fig. V.32). For the production of concrete this mixture is filled into the spaces between a layer of consolidated coarse aggregate. This may be followed by the spreading of a layer of smaller stone. The final surface is dependent on the amount of subsequent tamping.

A weaker grout can be used for subsoil stabilization ⁴⁹⁶.

The behaviour of the material in the mixer is shown in Fig. V.32.

An advance in the process of grouting consists in the use of a stable wetting or dispersing agent, which aids an ordinary cement-sand mortar to penetrate the coarse aggregate (of not less than 1-in. mesh) the more easily and with lessened segregation of the particles, and to be pumped through a considerable length of hose. The added material is a sulphonated or sulphated higher alcohol (such as octyl alcohol), or its water-soluble salts such as those of calcium or magnesium. The quantity used is usually about 0.01 per cent. of the weight of the cement. A considerable saving of cost is claimed in time, labour, and material ³⁶².

Surface Treatment.

To some the colour of concrete is unpleasant ; to motorists glare is sometimes troublesome, and the regular arrival of transverse black bands (the expansion joints) can be hypnotizing.

The surface treatment of concrete, therefore, is often desirable, and the more necessary the weaker (the more dust-forming) and porous it is. Except in the very densest material there are minute surface apertures that are best closed. Whilst it is true that wear as low as $\frac{1}{200}$ in. a year has been recorded on a good concrete under heavy traffic, there is always the risk that some portions of the surface may be less dense, and silicate treatment tends to ensure high resistance to wear throughout. A bituminous coating improves the surface in several ways, but adhesion though difficult has been achieved. When certain concrete surfaces are found to be slippery a bituminous dressing to hold chippings is desirable and, at the same time, such treatment may go so far as to constitute repair of a failure through disintegration. Treatment may usefully be given every three years.

Experience has shown that a hot tar dressing (with or without $\frac{3}{8}$ in. grit or $\frac{5}{8}$ in. slag, according to requirements) is most satisfactory, perhaps with a preliminary coating of creosote. Great care should be taken to remove dust, preferably by blowing with bellows or the exhaust from a car.

“ The first coat to a new road has usually been a thin coating of light tar, applied hot and gritted with a fine shingle such as Bridport grit. This wears off to a great extent during the year but helps the adhesion of the final coat. This last consists of B.S. tar with a viscosity of 80–150 seconds applied hot at the rate of 5–6 yd./gal. and gritted with $\frac{3}{8}$ -in. to $\frac{1}{2}$ -in. granite chippings rolled with a 6-ton roller, but not unduly crushed. It is desirable that the chippings should not be of too large a size and it seems

of the greatest consequence to keep traffic off the road for a period of 12 hours after spraying. This has been difficult in some cases as the police in an area such as this have, at times, objected to the traffic disturbance involved.

On the whole this method has proved effective. The one case of trouble has been during the very cold weather when, probably as a result of the salting of the carriageway, some patches of top dressing are loosened and have to be patched at a later date ¹⁴⁶.

An interesting method of treatment is that with *sodium silicate*, which can produce a dense skin of silicate to a depth of about $\frac{1}{2}$ in., preventing absorption of oily liquids but not interfering with the adhesion of bituminous dressings. It is less used to-day, because it is considered that if the concrete is dense the solution cannot penetrate, and if it can penetrate it is so porous that there is present too little cement for chemical action to take place.

This solution contains a higher proportion of silica than does the ordinary waterglass ⁹⁹, and its course of action is very complicated ^{122, 119, 120}.

The ratio of Na_2O to SiO_2 should be as 1 : 3.4 or 1 : 3.5; and the specific gravity should be 1.32 to 1.36.

The changes occur in two stages: first, reaction with the free lime in the cement, during which amorphous silica is set free—this is the setting phase; then, the amorphous silica turns partially crystalline and reacts with the silicate to form a more complex silicate—this is the hardening phase. Chemical research and microscopical examination has led to the identification of

small plates of tricalcium aluminate,

fine needles of monocalcium silicate,

colloidal monocalcium silicate (this plays an important part), and

large hexagons of calcium hydroxide.

The presence of organic matter, or the removal of soluble sodium salts by water, or the temperature varying outside of 13–29° C., acts adversely on the initial reaction and on the character of the silica formed.

The silicate solution must not be added to the gauging water, as the mixture then becomes quick setting and deficient in strength.

Whilst the rate of wear of good concrete may be as low as $\frac{1}{200}$ in. a year, there is always a risk that some portions of the surface material may be less dense than others, and the silicate treatment probably prevents uneven wear.

The method of application is usually as follows: About 7 days after the laying of the concrete in the case of rapid-hardening cement,

and from 14 to 21 days in the case of ordinary slow-setting cement, the surface should be thoroughly washed with clean water and brushed with a hard broom to remove all dirt and any laitance from the concrete. After allowing the surface to dry, the silicate of soda solution is applied by means of a fine rose watering-can and brush over surface with a soft broom. A further application should be made in 2 days, and a third application after a further period of 2 days. The concentrated solution should be thoroughly mixed in the proportion of 1 gal. to 4 gals. of clean water, a quantity which is sufficient for about 45 sq. yd. first application, and a rather larger area for subsequent treatments. The beneficial effect of this treatment varies in diminishing degree according to the composition of the concrete, such as 3 : 1½ : 1, 4 : 2 : 1, 5 : 3 : 1.

In cases where the surface is porous and has to be sealed, and a roughened surface is required, or unsightly cracks have to be covered up, treatment with *tar* or *bitumen preparations*, with or without chippings, has been tried. Very few of the surfacings have survived a few months' wear; probably a treatment with creosote oil followed by a dressing of tar has proved to be one of the most successful, or curing with emulsions after which the bituminous deposit persists. Some preparations containing mixtures of tar and bitumen have given great satisfaction.

Surfacing Mixtures.

Bitucrete ²⁵⁴, which is no longer made, but is intrinsically interesting, is a peculiar 'tigrone'-like mixture which is manufactured like concrete, except that a bitumen emulsion is substituted for the usual gauging water. The result is substantially a 4 : 2 : 1 concrete gauged with 7-12½ per cent. water and containing 7-12½ per cent. asphaltic bitumen (according to circumstances), a special emulsion being used containing about 50 per cent. of bitumen of 130 penetration. The maximum strength of the mass is obtained by keeping the quantity of cement and bitumen equal.

The resulting material is a concrete, crystallized as usual, and containing bitumen within the voids; this causes an elasticity that renders expansion joints unnecessary, and makes the final mass elastic.

It is claimed that the cement exerts its binding power independently of the bitumen. This cannot be completely true, but the most interesting observation under the microscope is that the growing needles of recrystallizing silicates have been seen to penetrate the film of bitumen surrounding the coarse aggregate (gravel) ³²². The mixture worked well but was not developed.

Cement-Bound Roads.

The first street to be constructed in this country by this process appears to be Bridge Street, Sandringham, in 1924. This type of construction is a water-bound road further consolidated by means of a cement mortar grout. The underlying formation should be blinded to prevent the mortar from being lost during the rolling required to bring it to the road surface.

The grout consists of a 2 : 1 sand-cement mixture. Like concrete, the finished surface should be protected until it is set. The desirable characteristics of the components are the same as those for concrete ; the stone to be of 2 in. or $2\frac{1}{2}$ –1 in., a coarse sand deprived of its finest materials, and standard slow-setting Portland cement, whether ordinary or rapid-hardening.

A 7–10 cu. ft. mixer is useful, and the roller should be of 7–10 tons. When a surface is rolled in half-widths, great care should be taken not to damage the partially set portion by overlapping the rolling on to it. Like concrete, expansion joints are desirable in some cases.

The gradient should not exceed 1 : 5.

The final surfacing is often so tough that a fracture goes through the stone as well as the mortar.

A coloured surface can be produced by the use of coloured cements.

This type of construction is suitable for housing estates rather than for carrying heavy traffic, and is inferior to the sandwich system.

Plant. Cement-sand mortars may be mixed in a roller-pan type of machine, in which balling becomes impossible. Mixers for batch units up to 12 cwt. are driven by a petrol motor up to 13 B.H.P., according to size and inclusion of a power loader.

Pre-cast Concrete Paving Blocks are no longer used. A block of hexagonal shape ³²³ was tried, making use of certain mechanical advantages in strength and stability, and bedded (by means of mortar) upon the reinforcement ($7\frac{1}{2}$ lb./sq. yd.).

Concrete Flags are controlled by B.S. 368 : 1936. They are available in eight sizes and are tested for transverse strength, rate of wear and absorption of water.

The use of clinker aggregate of crusher-run grading from $\frac{1}{8}$ in. downward began in Hornsey (London) in 1898 ⁸¹. The flags showed very desirable characteristics.

Characteristics of Concrete Roads.

Strength. When this is examined by the usual tests, it is found that compression, shear, and hardness are proportional to one another, as are tensile strength and bending. These two groups, however, have

no fixed relations to one another, owing to the difference of composition between the surface layers and the centre. Strength is influenced by the variation of internal stresses with the depth from the surface, and this is caused by changes of volume due to chemical, thermal, and hygroscopic action ²⁷³.

In the case of aluminous cements, quick dissipation of the heat that is so rapidly generated by chemical action does not lower the strength of the concrete ; but retention at high temperatures (100° for 24 hours) may do so. Also, a rise of water ratio by so little as 0.2 (0.8 to 1.0) may diminish the strength by 40 per cent. It has been observed that the strength of mixed concrete increases with the length of time of transport from a central mixing plant : for instance, an average 28-day strength, after 2½ hours travel, was found to be about 900 lb./sq. in. higher than at the time of loading.

It has been considered that the briquette strengths of concrete after 7 and 28 days give no indication of the strength reached after 6 months or more, but that they do give indications of the *comparative* strengths that will be developed ³⁰².

A comparison between the strengths of various cements has been compiled by the Lafarge Aluminous Cement Co., Ltd., on the basis of data supplied by the Building Research Station. This is shown in Figs. V.33 and V.34.

Another aspect of strength is the thickness required to carry different weights of traffic. Experience shows that, without reinforcement, safe thicknesses are :

Private roads, up to 16 ft. wide	.	.	.	.	.	6 in.
" " 16-20 ft. wide	.	.	.	.	.	7 "
To carry 5,000 tons a day	.	.	.	.	.	8 "
" " 10,000 "	.	.	.	.	.	9 "
" " 10,000 " " and more	.	.	.	.	.	10-12 "

Vibration. The outstanding character of a concrete road is its resistance to, rather than its absorption of, external stresses, resulting in the transmission and not the absorption of vibration. The possible association between this and cracking is suggested under that heading ; and the subject of vibration is also discussed elsewhere ; but here must be mentioned the special necessity that may arise of insulating the roadside structures from such vibration. To affect this, a bituminous joint is sometimes provided between the concrete carriageway and the kerb ; or a channel consisting of two or three rows of setts, jointed with bitumen. This acts also as an expansion joint.

Although the density of concrete favours the transmission of vibration it has the beneficial effect of incidentally decreasing the penetration of water. **Watertight concrete** results from careful

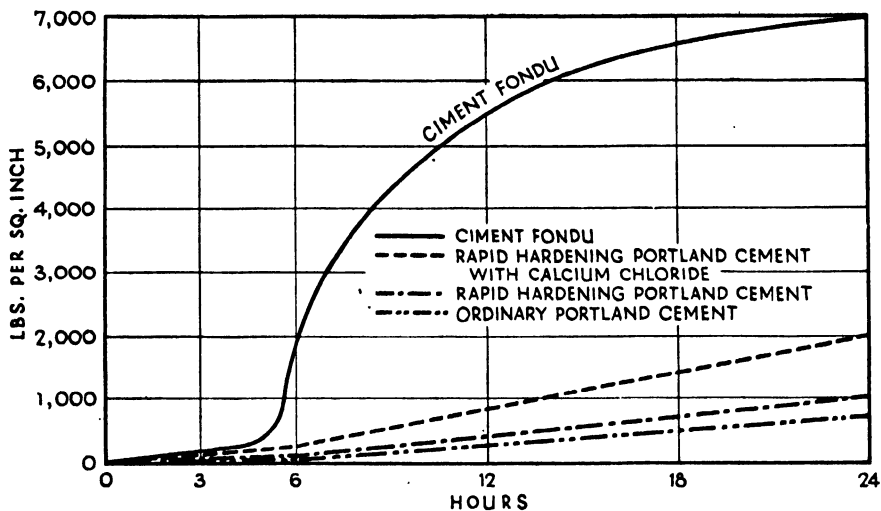


FIG. V.33.—Compressive Strength of 1:2:4 Concrete from 0 to 24 hours. Test Specimens gauged with a water-cement ratio of 0.60 stored in moist air.
This graph is compiled from data supplied by permission of the Director of Building Research.

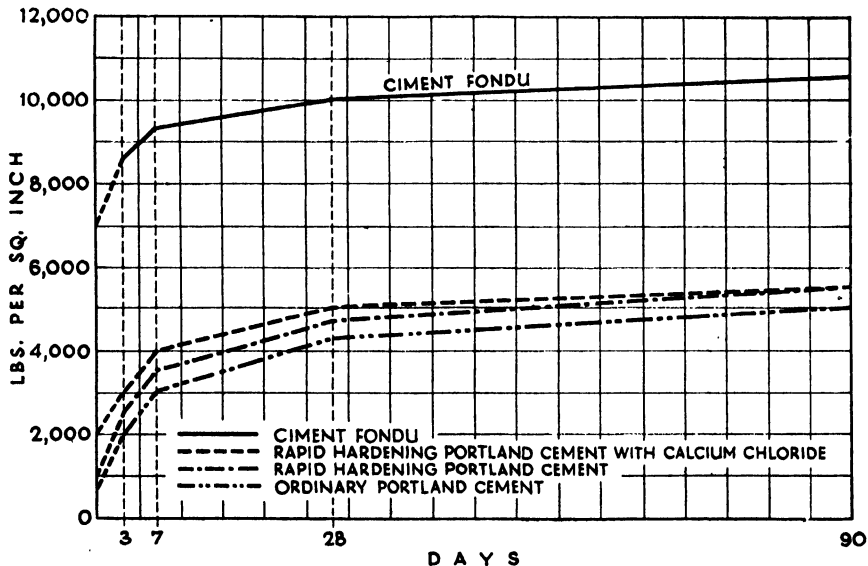


FIG. V.34.—Compressive Strength of 1:2:4 Concrete from 1 to 90 days. Test Specimens gauged with a water-cement ratio of 0.60 stored in air at 64° F. and 65 per cent. relative humidity.
This graph is compiled from data supplied by permission of the Director of Building Research.

attention to the use of sound aggregates, correctly graded and accurately proportioned to workable mixtures ; a limited amount of water, efficient laying and tamping, and careful curing. Certain admixtures favour this (see also *Porosity*, below).

The addition of bituminous substances is not current practice, though advantages are claimed for it, such as increased impermeability and, thereby, reduction of shrinkage and deterioration.

The bitumen could be introduced with the cement or added to the mixture on the site ⁴⁷⁸. *Bitucret* (q.v.) was a surfacing, in which bitumen emulsion took the place of plain water. Laboratory tests showed that precoated chippings could be added to the aggregate with advantage to strength ⁴⁷⁹. Resistance to the passage of **heat** increases rapidly for 200 days, and less rapidly during 1,400 days ²⁷⁵.

Slipperiness. The slipperiness of concrete has been described in flatly contradictory terms. This is quite in the best tradition of thought and experience regarding many road problems ; but the basis probably lies in difference in certain details of construction resulting in a very smooth hard surface or one that wears a trifle—or has its mortar brushed out of the surface before setting—leaving the aggregate slightly ‘proud.’ It also depends on the character and size of the surface aggregate and upon the type of construction. Care must be taken, especially on a gradient, that the selected aggregate does not wear smooth. Crushed setts, but not crushed cobblestones, are suitable.

Slipperiness due to icing is often dealt with by spreading some form of salt on the surface, on the principle that the freezing point of a solution is below that of the pure solvent.

Great care must be exercised on concrete roads, as cement is a chemically active substance, and contact with other chemicals may cause trouble. Further, imperfect concrete allows penetration of the salt solution to the iron reinforcement, where further chemical action can occur.

Much work has been done on this problem, and on the life of concrete in contact with sea water. Dilute solutions of salt act like pure water and remove lime and, with higher concentrations, this is more active. The effect is less with older concrete ⁴⁸².

This has been repeatedly substantiated ; but the most scientifically controlled investigation has been made by the Road Research Laboratory at Harmondsworth. There it was found that :

Salt should not be used alone, as dangerous concentrations may occur ; but instead a mixture of salt and sand. For thick ice,

this should be in the proportion of 1 salt to 8 sand, and applied in the worst cases as much as 2 lb./sq. yd. For thin ice, 1 salt to 25 sand, applied at the same rate per area, is suitable. Other inert material can be used in place of sand. And if the mixture can be heated to 300° or 400° F. before application, a greatly improved result is obtained ⁴⁸³.

Observation over a number of years has been made in Sweden ; when it was found that the most deleterious concentration of salt was 5 per cent. and of calcium chloride was 3.5 per cent. This may be due to the separation of ice at a particular critical temperature ⁴⁸⁴.

The maximum practicable **gradient** for concrete roads is quoted as being about 1 in 9, but for any gradient approaching this special precautions must be taken. Ordinarily 1 : 12 should not be exceeded.

Irregular Surface Conditions. The origin of irregular surface conditions in concrete is obviously entirely different from the ripples and waves in asphalt. It may result from variability of strength of the subsoil, due to the presence of varying proportions of water, or possibly resulting from alternate bay construction ; from intermittent tamping or wear of the tampers when not iron-shod ; irregularity of laying ; or laying of too small slabs that rock.

Considering individual slabs, sagging may result on a weak subsoil and curling may occur to the extent of 1½ in. Warping, and therefore an irregular surface, may be due not only to differences of temperature as between the slab and the subsoil, but as between different depths of the slab within itself. (See also ²²².)

Breakdown. Concrete roads have their defects like the rest, so that they are often laid at a level which will permit subsequent surfacing with another material. Deterioration of concrete may result from too much gauging water, leading to porosity and hydrolysis of the cement ; and to the penetration of water into cracks and its expansion by freezing—this is also possible in any chalk pebbles that might have been included in the aggregate ⁴⁷⁷, also, from the action of ground water containing humic acid (as soluble organic impurities are usually termed), or the oxidation products of sulphides ; to weathering, due to imperfect materials and their manipulation ; to the action of sea and other water containing salts rendered more active by the presence of chlorides ; and to alkalis produced by the reaction between cement and soluble sulphates ²⁸⁸.

Probably the most troublesome defect in concrete roads is *cracking*, the origin of which lies in the effect on tensile strength of various details of proportioning, mixing, laying, and curing controlling contraction during setting. In particular it may result from imperfect

materials (cement containing too much lime) or from warping due to temperature changes.

It may also be due to fatigue, resulting not only from the curling and uncurling of the slab due to temperature changes, but also from vibration. Concrete transmits vibration, and does not absorb it, so that it is continuously quivering under traffic. Its strength results from its interlacing crystals, which constitute innumerable tiny crystal-girders, and it is possible that these may break down when fatigue from prolonged vibration has become excessive. The fact that cracks usually appear during about the first year of the life of a concrete road appears to indicate that the effect of vibration is important in the early stages when a road is taking its 'bearing.'

A successful system of eliminating 'macro-cracks' is the separation of the concrete into small masses, by laying it in a metal mesh, of the type used in asphalt construction for a different purpose. (See also *Metal Roads*.)

A form of cracking, more superficial but not less troublesome, is that of *crazing*. This depends on the simultaneous action of two influences: (1) preliminary irreversible shrinkage and subsequent reversible shrinkage and expansion due to alternate drying and wetting, and (2) these changes taking place in presence of atmospheric carbon dioxide⁴⁰². It is facilitated by the presence of laitance. (See also *Water-Tight Concrete*, above.)

Apart from the assistance afforded by macro- and micro-cracks, penetration of water may occur from a general *porosity*, which results from a large number of influences attending the preparation, laying, and curing of the concrete. This has been examined in great detail²⁹⁰, but only the more important conclusions can be referred to here: too much and too little water favour permeability; sand has a greater influence than gravel, that between the 30- and 40-mesh sieves (about $\frac{1}{16}$ th in.) usually giving the greatest density; powdered sand, hydrated lime, powdered slate waste, and red mud are examples of effective added materials; prolonged ramming is not sufficiently effective to justify its cost; trowelling is useful with dry mixes; wire brushing of the surface is definitely bad; permeability decreases with age up to one month, after which change is small; good curing conditions are of the highest importance with Portland cement, but less so with aluminous cement.

Some engineers fill cracks with bitumen immediately they appear, others deal with the matter as a yearly routine. If one of the duties of a road surfacing is to protect the subsoil, it seems to be essential that cracks should be closed as soon as detected.

It must be remarked that in conversation with concrete-road

enthusiasts, the evil effect of the percolation of water to the foundation is minimized.

Patching and Reinstatement.

It is often difficult to make a thoroughly sound job. The work should be done with the greatest care, the hole being first cut out with sides slightly sloping inwards from top to bottom and left rough to form a good key. Dust should be thoroughly removed with a soft brush, by washing, or preferably, where this is practicable, by a blower. The sides should in any case be well wetted and then coated with a cement wash. The new concrete should be well tamped to obtain maximum consolidation and reduce shrinkage.

Reinforcement.

The reinforcement of concrete is a subject upon which there has been a wide divergence of opinion. Some engineers use no reinforcement; others adopt a single reinforcement at the top or the bottom, or both. An inquiry (in 1933) elucidated that 12 per cent. of engineers used no reinforcement, 2 per cent. used it at the top, 62 per cent. at the bottom, and 24 per cent. at both.

Reinforcement does not prevent cracking in general (though corners can be so protected), but it holds the fractured portions together and so prolongs the life of the road. The mechanical reactions between the concrete, its reinforcement, and the subsoil are complicated.

The quality and nature of the reinforcement, whether of bar or wire, is laid down by B.S. 785 : 1938; and similar properties for the fabric, whether of hard drawn steel, twisted steel, or expanded metal, are controlled by B.S. 1221 : 1945. The expanded metal included in this specification is specially suited for concrete reinforcement, whereas B.S. 405 : 1945 deals with expanded metal for general purposes.

The main difficulty in determining the form and extent of reinforcement required, lies in the foundation conditions varying largely, not only in different localities, but often in the same road, and even within small areas of the same road. This trouble is becoming increasingly mitigated through use of some method of soil stabilization; so much so, that there is a tendency for concrete slabs to be made thinner than before. But apart from the varying character of the natural subsoil, there are few roads in urban areas in which trenches of differing depths and widths have not been excavated, which causes considerable increase in the problem of adequate advantages of reinforcement.

In such cases it is impossible to determine the character and extent of the stresses to be resisted by a slab of concrete forming an all-

concrete road, or of a concrete road foundation to carry a wearing surface of some other material. Moreover, the loading will vary both in position and extent, and such factors as impact and vibration are almost impossible to calculate. In addition, expansion and contraction will vary the nature and extent of the stresses from time to time.

Efforts have been made to evolve formulæ for use in the design of concrete roads, but none of these appears to be of any great practical value, or has been generally adopted.

One writer ³⁴⁹, discussing the relative advantages of three-way and two-way reinforcement, expressed the opinion that: “a perfectly homogeneous and elastic slab, *laid on a uniformly yielding foundation and subjected to a load uniformly concentrated at the centre of the slab*, would deflect, in the manner of a beam fixed at its ends, along any cross-section, and at any point in the deflected area the directions of the stresses would be radial and circumferential. In dealing with a concrete slab, there is little doubt that experience is a more reliable guide than theory, but *under conditions similar to those described above*, it would appear that the ideal reinforcement should consist of radial and circumferential bars, and that this ideal is more nearly approached by a three-way than a two-way reinforcement.”

It will be observed that the whole force of the argument depends upon the words in (the Authors') italics, which assume certain definite conditions, seldom, if ever, found in practice.

The writer is undoubtedly correct in suggesting that in this matter “experience is a more reliable guide than theory”; and experience, except perhaps in certain favoured localities—such as the Lancashire districts—appears to support the use of reinforcement.”

It is doubtful, however, whether the advantages lie merely in the increased strength of the slab. The effect of reinforcement in reducing warping, preventing or controlling cracking, increasing resilience, and in holding the concrete together and preventing slipping after cracking has taken place, may be of equal or greater value.

If strength is the only or main object, then double reinforcement would appear to be indicated, as it is generally impossible to forecast where, in the different parts of a road, tension will be at the top or at the bottom of the slab. In fact at one time a portion of the slab may be in tension, and at another in compression, and this may even be brought about by temperature and moisture changes alone.

In these circumstances, it is little wonder that individual opinion and prejudice plays an important part in determining whether and what reinforcement should be provided.

For instance, whilst double reinforcement appears to have shown a definite advantage over single reinforcement, either top or bottom,

in preventing transverse cracks, particularly with 6-in. slabs, it is reported that the only set of slabs developing large corner cracks were the 6 in. with top and bottom reinforcement.

At the same time it appears to have been established that top reinforcement alone is of no ultimate value as a crack preventative, whereas bottom reinforcement alone has an appreciable advantage, the cracks in unreinforced concrete 8 in. thick being about 50 per cent. more than in similar concrete with bottom reinforcement.

It must be recognized, however, that these results were obtained in connection with experimental work carried out with the greatest care, for the purpose of research, and it is by no means certain that similar effects would follow where different materials, or methods, were used or other conditions varied.

Many advocate reinforcing more heavily in the longitudinal direction than transversely, but having regard to the fact that the more important trenches are usually longitudinal, it would appear that reinforcement at right angles to these trenches is at least as necessary as in the other direction.

It is held by some that the value of reinforcement is greatest during the early life of the concrete, when it takes up some of the internal stresses.

Reinforcement at corners, particularly where these are acute, appears to be beneficial in preventing cracks. The value of expansion joints is considerably reduced by carrying reinforcement across the joint.

In any event, it is of the utmost importance that the concrete should be packed tightly around the steel, which should everywhere be protected by concrete at least $1\frac{1}{2}$ in. in thickness.

In many cases when the reinforcement was not in the position specified ³⁵⁰, it was found to be below the bottom of the concrete. The concrete below the bottom reinforcement was often honeycombed and insufficiently consolidated. In such circumstances the use of reinforcement is, of course, simply a waste of money, and moreover corrosion of the steel may lead to definite trouble.

The greatest care should also be exercised in laying the reinforcement and consolidating the concrete where a thin slab is being laid, as, for instance, is sometimes done where it is to be surfaced with asphalt in substitution for wood paving or setts. The removal of the wood blocks and of the floating will often provide a total depth of $5\frac{1}{2}$ to $6\frac{1}{2}$ in. for new construction. In many cases very satisfactory results have been attained, under such conditions, by laying 2 in. to $2\frac{1}{2}$ in. of asphalt upon concrete 3 in. to 4 in. in depth, reinforced with light steel fabric (about 3 lb. per super yard), but the work must be thoroughly well done, particularly the consolidation of the concrete.

In connection with the removal of tramways and reinstatement of roads during the war period, when suitable reinforcement was unobtainable, the area of the track (16 ft. 6 in. wide) in some of the important roads of London, was successfully paved with asphalt upon $3\frac{1}{2}$ in. to $4\frac{1}{2}$ in. of new concrete, unreinforced (see p. 277).

The nature and quantity of reinforcement is still a matter for controversy.

The interlocking of concrete with a notched bar may be considered to concentrate strain on the concrete to too great a degree. The twisted square bar (twisted cold and interlocked without welding) may also concentrate too great a transmission of force along the edges.



By the courtesy of The British Reinforced Concrete Engineering Co., Ltd.

FIG. V.35.—Square-mesh Reinforcement in Sheets.

The smooth rod may give doubts as to the completeness of bond with the concrete; and expanded metal may be considered to have the strength only of the resistance to shear across a series of narrow cross-sections. Thus, many of the successful types of reinforcement for concrete are open to serious criticism. At any rate, whenever there is complete bond between the two, there must be a serious strain on the concrete if their coefficients of expansion are not *exactly* the same, and these forces can be very great whether they originate from temperature or chemical reaction.

Whatever the nature of the reinforcement may be, it is of high importance that it should lie flat in position as may be seen in Figs. V.35 and V.36. Mesh reinforcement is largely used, and is both convenient and effective, but should it be fused at the contacts or

left free ? The unfused allows of a certain freedom to adaptation to curvature and is easier in handling ; but the fused mesh preserves regularity of shape and therefore regularity of distribution of forces.



By the courtesy of The Expanded Metal Co., Ltd.

FIG. V.36.—Showing Stages in the Work.



FIG. V.37.—Lindsay's Patent Surface Fabric being laid at Langside Divisional Central Station for Glasgow Corporation Lighting Department.

When expanded metal is used (Fig. V.37), it is governed by the British Standard Specification 405 : 1945. (See also *Metal Roads, Cellular Mesh.*)

The mesh of reinforcement to-day, made from rod or wires, is

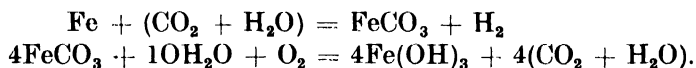
almost all square or oblong. Of the two, the square mesh is more commonly used as the workmen can walk upon it without disturbing the concrete, but for larger jobs the oblong mesh is preferred as it can be more easily rolled for delivery. It is recommended that the transverse rods should have at least one half the cross-sectional area of the longitudinal.

Much valuable research has for long been done by the Road Research Laboratory on the behaviour and properties of reinforced concrete, and this has been published in Reports of the Board.

Concrete Reinforcement : Corrosion.

The acid corrosion of iron reinforcement is practically prohibited by the surrounding cement, which is alkaline. If concrete were dry and water-tight, there would be no corrosion. If pure water penetrated to the iron, there would still be only the minimum of attack upon it. If, however, the water were impure, certain possibilities arise, according as the water were acid or contained certain salts in solution.

If carbon dioxide were in solution, corrosion would only result from the action of the proportion that escaped removal by the lime in the fissure. This would cause the iron to be actively attacked, the more so as the reaction goes in a cycle and the carbon dioxide continues to exert its action indefinitely :



Humic acids in peaty waters are alone usually too weak to attack, although occasions have been known when cast-iron was heavily attacked by such waters. Sulphur waters attack iron, converting it into iron sulphide, which sets up electro-chemical action between the patches of sulphide and the metallic iron. If the sulphides in the water were partially or wholly oxidized to sulphuric acid, or if the iron sulphide became oxidized, corrosion would be rapid, with the formation of soluble sulphate of iron.

It is at any rate theoretically possible for nitric acid to be formed by the effect of lightning on the atmospheric gases, in sufficient quantity to attack, not only the iron, but also the cement.

Certain salts such as ferric chloride and nitrate and magnesium chloride and sulphate may cause serious corrosion through the action of water liberating a small quantity of hydroxide or oxychloride of the metal and free acid ; and as this free acid is removed by combination with the iron, a further amount is liberated and corrosion continues until conversion is complete. Ammonium nitrate attacks iron actively ; and calcium chloride in presence of air may act similarly.

The salts of heavy metals attack iron primarily by replacing the iron by themselves and the iron taking the place of the metal in solution. Under road conditions such attack is unlikely, and only copper might in rare circumstances be dangerous.

The effect of stray electric currents would be to accelerate anodic attack—the corrosion by acids. All reactions mentioned become hereby exaggerated and the protective action of the alkalinity of the cement would be the more rapidly overcome.

Of all the possible modes of attack that have been mentioned that producing rust is by far the most likely. The villainy of this type of corrosion is that rust occupies three times the volume of the original iron, and this expansion is enough to crack the concrete, the force being 4,700 lb./sq. in.³²¹. (For a commentative description of concrete road making, see ⁸⁰.)

CONCRETE MIXING PLANT

The mechanical plant for road concrete is well known; and a survey of the products of the numerous and very high-class engineering firms of this country discloses a close general similarity. At the same time there is evidence of the most careful examination being made of all details for the sake of increased efficiency and speed of working. The sizes for road work range from a batch output of $3\frac{1}{2}$ to 14 cu. ft., requiring approximately $\frac{1}{2}$ to 12 h.p. Much simplicity has been introduced into the design of batch type concrete mixtures by B.S. 1305 : 1946.

Concrete may be mixed at a central plant, or on the job. The former practice is to be preferred as the ingredients are combined in controlled and correct proportions, whilst in the latter there is ever possible much error through lack of conviction of the necessity for accuracy. Another influence of choice is the distance of the plant from the job, the cost of transport, and the care to be taken to keep the concrete properly mixed during transit.

It has been found that concrete which is kept in motion can safely be used at least 2 hours after mixing. Where the concrete is being laid within say 4 miles of the point of mixing, special means for keeping the concrete in a state of agitation during transit are not necessary, but for longer hauls a motor vehicle mounted with a conical or cylindrical drum, fitted with internal blades, is used for conveying pre-mixed concrete. The drum revolves slowly as the vehicle is travelling and keeps the concrete in continuous motion. Usually the drum has a capacity of from $1\frac{1}{2}$ to 2 cu. yd. and the discharge can be controlled to facilitate distribution of the concrete.

Cement and aggregate in the required proportions are loaded into the drum at the central depot, and either there, or at a short distance ²⁴⁹—say about 5 minutes from destination—the mixer is put into operation and the correct amount of water added.

It will be observed that the main difference between the two methods is that in the first the concrete is mixed at a depot before loading into vehicle and in the second freshly mixed concrete is delivered. Within distances not involving more than say 2 hours' delay there appears to be little difference in the quality of the concrete, though there may be a tendency towards de-aeration. Central mixing involves greater outlay at the depot, but the vehicles are lighter and less expensive.

A serious disadvantage is the amount of capital tied up in expensive lorry-mixers which are unused owing to irregular working.

It is in details that differences and refinements of plant are seen. Some plants are fitted with solid or pneumatic rubber tyres ; some are constructed as trailers ; some are of the tilting and non-tilting type. Rotation of the drum may be effected by means of rubber-shod rollers instead of the usual gearing ; and roller and ball bearings are supplied to the drum spindle. A hopper may be batch-measuring, and may be operated oil-hydraulically ; the loader may be streamlined and automatically shaken to facilitate complete emptying. The water tanks may be controlled and worked automatically : it is very desirable that this practice should be closely adhered to.

An excellent 'review on present-day knowledge and practice' is that of F. N. Sparkes and A. F. Smith ³¹².

There has been considerable development for some time past, in the design of mechanical road-making plant, largely under American stimulation. This will certainly continue, especially for work on so large a scale as to justify the use of such big plant, as for instance, the building of the country's motorways.

Such plant is specially suitable for dealing with the increasing favoured dry concrete of low water-cement ratio.

The continuous mixer is the logical development of the need for large outputs, and depends for its success on the close control by the proportioning devices of the various ingredients. This success seems to be undoubted, if those in control of the plant select and feed the components properly ⁴²⁴.

It is interesting to note that the Norwegian Holter System was the final outcome of a long series of laboratory experiments on the nature of adhesion within the concrete mass, begun by Dr. Michaelis in 1903. Superficially, the machine is not very different in general design from the more modern plant though there were several very different details ¹⁴⁷.

One of the most recent British concrete spreaders uses a rotary helix to lay the mixture, after which it is vibrated at 4,000 cycles/min., and the operation ends with a finishing roller. The whole is driven by a petrol engine, and the machine runs on temporary rails ⁵⁹⁹.

A notable development in concrete spreading and compacting machines is that of Messrs. Stothert & Pitt. (See Fig. V.31).

Concrete Roads for Private Streets.

Concrete roads are often particularly useful in connection with the development of new estates.

It is becoming the general practice in some localities to lay down a concrete carriageway before building operations commence, and if the work is thoroughly well done it is often the most economical course to follow. In this case, all sewers, gas, water, and other mains and all connections must be made before the road is constructed, and in any event the approval of the highway authority to the procedure should be obtained beforehand.

In many cases arrangements are made for the authority to provide supervision at the cost of the estate owner, on the understanding that the carriageway will be accepted after the building is completed, without extra cost to the frontagers, unless it is damaged.

The main advantage of this system is that it provides a good clean road for the transport of materials during building, and for the use of the occupiers of the new buildings, from the time the first building is inhabited. The inconvenience and unpleasantness, which is so often associated with new streets prior to the final making up by the local authority, is largely avoided.

In addition, the cost of temporary and often ineffective work during the process of development is saved. Care should be taken to prevent damage during the progress of building, particularly to the edges of the concrete, as otherwise difficulties may arise with the local authority in connection with the taking over of the road.

For ordinary residential streets which are not likely to carry heavy traffic, a thickness of concrete of 6 in. with or without light reinforcement is usually satisfactory, upon a good well-drained subsoil. A layer of clinker or ashes below the concrete where the subsoil is not satisfactory is of considerable value. This layer should be wetted and rolled before the placing of the concrete.

Model Specifications—Nos. 1 and 2—of the Institution of Municipal and County Engineers, provides for the construction of sub-bases of low-quality concrete varying in thickness from 2 in. to 6 in. according to the nature of the soil. These Specifications and the other two in the

series (Nos. 3 and 4) may be taken as supplementary to the earlier specification prepared by the Institution and approved by the Ministry of Health ³⁵⁶.

BLOCK PAVING

METAL ROADS

Two forms of construction in which metal is used at or near the surface have been in limited use : all-metal paving, and paving comprised of metallic cellular mesh filled with bituminous material or cement concrete.

The all-metal *cast-iron* surfacing has been designed to carry the very heaviest and most wearing traffic and has been tried in many

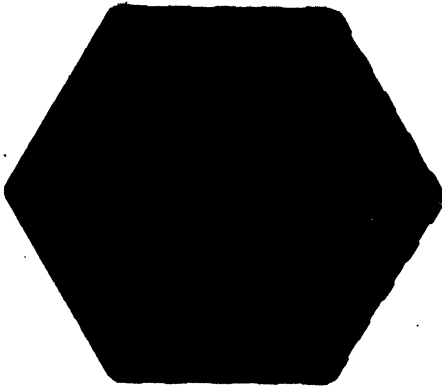
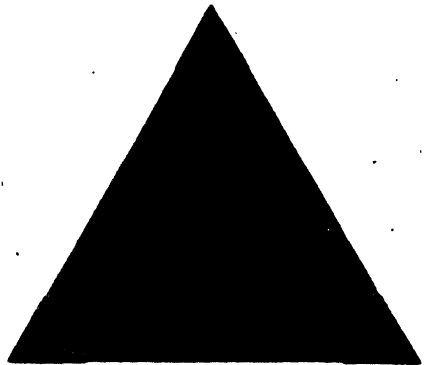


FIG. V.38.



By the courtesy of Iron Roads, Ltd.

FIG. V.39.

Cast-iron Road Blocks.

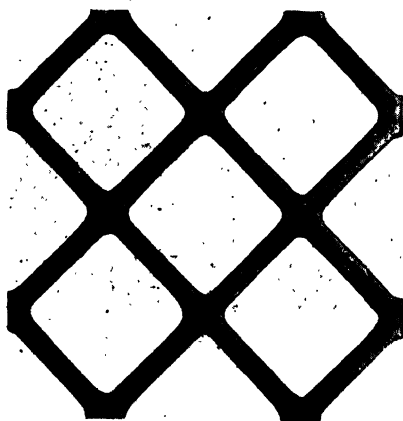
parts of the country. The first type was the triangular block ¹⁰⁸ (of which the latest form is shown in Figs. V.38, V.39), which was manufactured for the patentees by the Stanton Iron Works, Ltd. It consists of a triangular, hollow block, 2 in. deep, which is laid on bitumen over concrete, with a bitumen filler between each block. Being triangular, it will not rock under traffic. The surface is provided with regular projections in order to render it non-skid. For horse traffic these projections are made of slightly unequal height so that foothold may be more easily obtained. The block can be faced with aluminium to form a traffic white line.

Later, the manufacture of this block was taken over by the patentees themselves, and supplied under the title of the 'Tripedal

Unit System.' The Stanton Iron Co. subsequently developed their square internally strutted block ¹⁰⁹, but have ceased manufacture, owing to lack of demand during the war.

A comparison between the two systems is not easy, as equivalent figures are not available; but the following information has been supplied: *Tripedal*. Triangular block, 12-in. base, weighing 11 lb. A gang of four men can lay 1 sq. yd. in 5-6 minutes. 200 castings go to 1 ton, and this covers 10 sq. yd. *Stanton Iron Roads*. Square block, about 1 ft. square, weighing about 26½ lb. Blocks can be laid at the rate of 1,000-1,500 a day. The raised studs are now hardened.

The *cellular mesh* type of metal surfacing has several functions.



By the courtesy of Messrs. Gould's Foundries, Ltd.

FIG. V.40.—Heavy Metal Grid for Reinforcing Plastic Surfacings or avoiding Cracks in Concrete.

It is used principally for preventing plastic mixtures from moving under such severe strain as occurs at 'bus stops and on an incline; or, as a means of limiting the area of breakdown, such as potholes or cracking of concrete; or, assisting it to support the weight of traffic, the interstices being filled with some material suitable for producing an even road surface. When concrete is employed, there is no question of expansion joints; but in some cases concrete is not an ideal material for the purpose. A characteristic example of the cellular mesh is seen in Figs. V.40 and V.41.

Another type of surface reinforcement consists of a lattice of long steel strips held in position by cotter pins, and laid on flat steel bearing strips on the surfacing to be reinforced. It is sufficiently flexible to be rolled up. When used with asphalt, it is supplied already coated with bitumen to ensure good adhesion with the type of asphalt that is worked into the interstices ⁴⁵⁶.

The various forms of such surface reinforcement aim at solving the problem of spreading traffic shock over a wide area of foundation and of diminishing vibration by absorption, reducing the effects of change of temperature, and of preserving mechanical continuity. The depth of the mesh may reach 1¼ in., according to the design and purpose.

WATER-BOUND ROADS

The essential difference between the road-making principles of Telford and Macadam, at the beginning of the nineteenth century, was the same as that which exists at the present time—the difference between rigid and resilient roads.

Telford took the greatest care to provide a very firm foundation, consisting of courses of flat stones, 7 in. deep and not more than 4 in.



By the courtesy of The Limmer and Trinidad Lake Asphalt Co., Ltd.

FIG. V.41.—‘Surfastal’ Steel Mesh, being filled with Asphalt (‘Ferrophalt’).

wide, set on edge after careful trimming, with small stones and chips hammered into the interstices. On this he put 6 in. of hard stone and, after careful consolidation, a further $2\frac{1}{2}$ in. of smaller stone and gravel. The camber made the road 4 in. higher in the centre than at the sides. This was the construction of the Holyhead road, completed in 1830.

Macadam (who, be it noted, spelled his name ‘McAdam,’ and he ought to know) condemned Telford’s foundation as being unnecessary, and even detrimental, because movement of the foundation caused

opening of the surface. He preferred to lay, on the elastic soil, 10 in. of broken stone of which no piece weighed more than 6 oz. 3-6 in. was laid and left for consolidation by traffic, after which the final thickness was made up. The first 5-6 in. might consist of flints, with granite on top. Where Telford bound the surface with gravel, Macadam would have none of it, relying on the interlocking of the fragments together with the fine material from normal wear to give a firm surface.

Both men insisted on good drainage as being of prime importance.

To-day, the practice of Macadam has prevailed, though the details of his method have been departed from to a great degree—his name being associated with any water-bound broken stone construction. In fact, the International Committee made the request that the word macadam should be used as little as possible, as it meant so many different things in the various continental countries.

In this country, the construction of this type of road varies in different districts largely in accordance with the materials locally available.

In the north, and when natural rock is plentiful, the foundation is usually formed of pitching laid very much as advocated by Telford. Where gravel is produced locally the foundation is often composed of 6-12 in. of this material. In districts where chalk of suitable quality is easily obtainable, this material is often used. In the London area hard-core, consisting mainly of broken bricks or brick rubbish from the brick fields, is largely used, and when of suitable quality and thoroughly rolled it forms an excellent foundation for macadam roads to carry light traffic.

The use of water-bound macadam has diminished in great degree during recent years, and tarmacadam, or grouted or semi-grouted macadam, has been substituted. Water-bound macadam and even water-bound flints are, however, still laid in some localities, but are almost invariably treated with some bituminous surface dressing. It is doubtful whether, taking a long view, this can often be justified, having regard to the inexpensive form of bituminous and cement surfacings now available which are of a more lasting quality.

Heat Treatment for Soil-Road Construction.

This Irvine (Australian) process is mainly of value in areas where the transport of ordinary road-making materials is difficult.

A suitable soil is strongly heated, whereby it is converted into lumps of a brick-like material which can then be consolidated by rolling into a surface comparable to that of a gravel road ⁸¹.

WOOD PAVING

(For early history see ⁵³⁴.)

Wood paving was first used experimentally in New York and Philadelphia in America in 1835, in this country it dates from the laying of the first roads in Whitehall and in the Old Bailey, in 1839. By the end of 1873, the following had been put down ¹³⁵:

Pavement.	Length. yd.	Superficial Area. yd.
Carey's	134	946
Improved Wood	701	9,745
Ligno-Mineral	27	410
Mowlem's	171	1,053
Stone's	26	284
Total	1,059	12,438

Between 1872 and 1879, the only company of any size—The Improved Wood Pavement Co. (that was originally started to work Bethell's method for creosoting timber)—laid 250,000 sq. yd. in London and the Provinces.

The problems in wood paving is to obtain wood that is suitable to traffic requirements (the soft woods have been found to be more desirable than the hard), and to preserve the blocks immovably in position and in a water-tight condition, under traffic.

Experience has shown that, in this country, the most satisfactory wood is the *Pinus sylvestris*, commonly known in the trade as red or yellow deal, and the British Columbian Pine. It is a well-known fact that a considerable variation of texture and grain occurs in the Scandinavian Pine arising from the geographical position in which it is grown, and this is indicated by its port of shipment. The best results are obtained from timber from the Northern ports, as this is found to be more even in grain and texture than that from the Southern ports.

It is desirable that a moisture content in the wood shall not much exceed 16 per cent., and this is attained naturally if the wood be kept in proper storage for a period of two years.

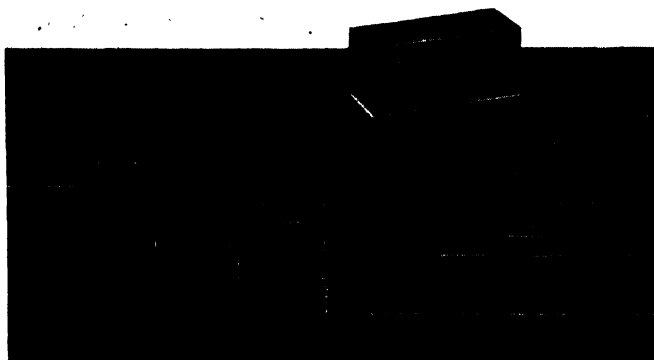
British Columbian Pine (*Pseudotsuga taxifolia*, less accurately *P. Douglasii*) was being extensively used in Cannon Street, London, some years before the 1939-45 War. Its use increased steadily since its introduction in 1922 when the importance of special care in preparation and selection was better understood.

A large number of other timbers have been tried at various times ;

such as elm, beech, oak, and sweet chestnut among the home-grown timbers, and Baltic whitewood and spruce, red pine, and hemlock from Canada ; red gum, blue gum, stringy bark, iron bark and black butt from Australia ; and kauri pine from New Zealand. None of them gave such satisfactory service as regards durability (including resistance to abrasion and to decay), evenness of wear, freedom from excessive shrinkage or swelling, and cost.

At one time large quantities of jarrah and karri blocks were laid, because, being hard, they were expected to behave well ; but excessive expansion and contraction and unevenness of wear resulted in their use being practically discontinued for road work.

In addition, the softer woods protect the foundations by their absorption of the cruder traffic vibrations.



By the courtesy of Firmosec, Ltd.

FIG. V.42.—Example of Wood Block with permanently attached Splines for preserving spacing.

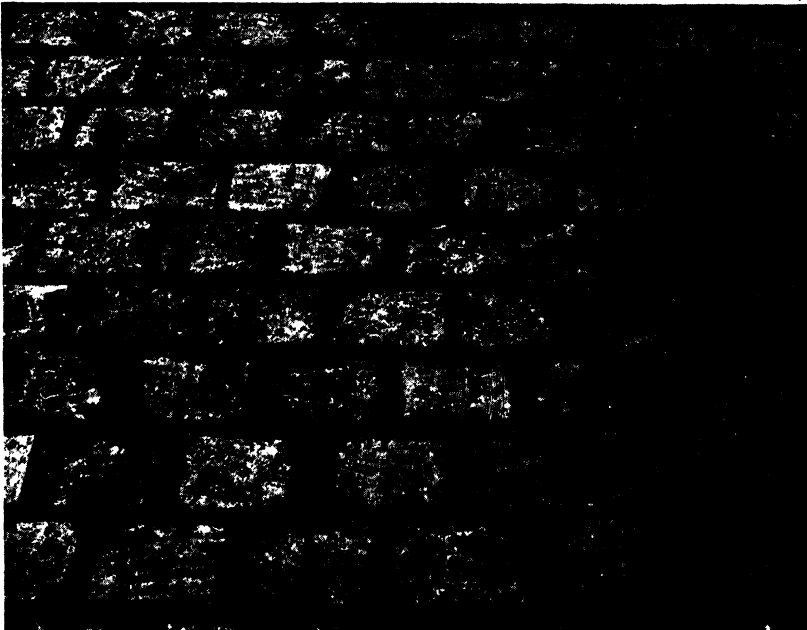
Amongst the possible home sources of wood blocks, there is only the Scotch fir that might be used, but the more desirable and harder growths are too widely dispersed in small areas for the industry to be organized on a competitive basis.

Blocks. The size of the blocks varies from 7 in. to 9 in. in length ; the width is usually 3 in., and the depth from 4 in. to 5 in., the more usual being $8 \text{ or } 9 \times 3 \times 4 \text{ or } 4\frac{1}{2} \text{ in.}$

In the search for the way to convert a collection of blocks into a coherent and water-tight pavement, a number of different forms have been evolved. At the present time, Fig. V.42 shows the most widely used block ¹³⁶. It was first laid at Aldwych in 1926. Such a block allows of a permanent spacing, with ease of grouting without the fear of air-locks. It is claimed that this wide spacing holds grit and, therefore, the type of wood paving is non-skid in all but exceptional circumstances.

Experiments with half-length blocks of $4\frac{1}{2}$ in. in place of 9 in., and with $\frac{3}{8}$ -in. splines instead of $\frac{1}{2}$ in., have produced a paving the joints of which can be partly filled with bituminous grouting material and the remaining space with precoated chippings. Experience since 1937 shows that perfect waterproofing is effected, whilst avoiding covering the whole surface of the paving when the filling of joints only is required. (See Fig. V.43.)

Jointing and dressing material may consist of a cut-back bitumen (with or without the addition of one or even two fillers to increase



By the courtesy of the Acme Flooring & Paving Co., Ltd.

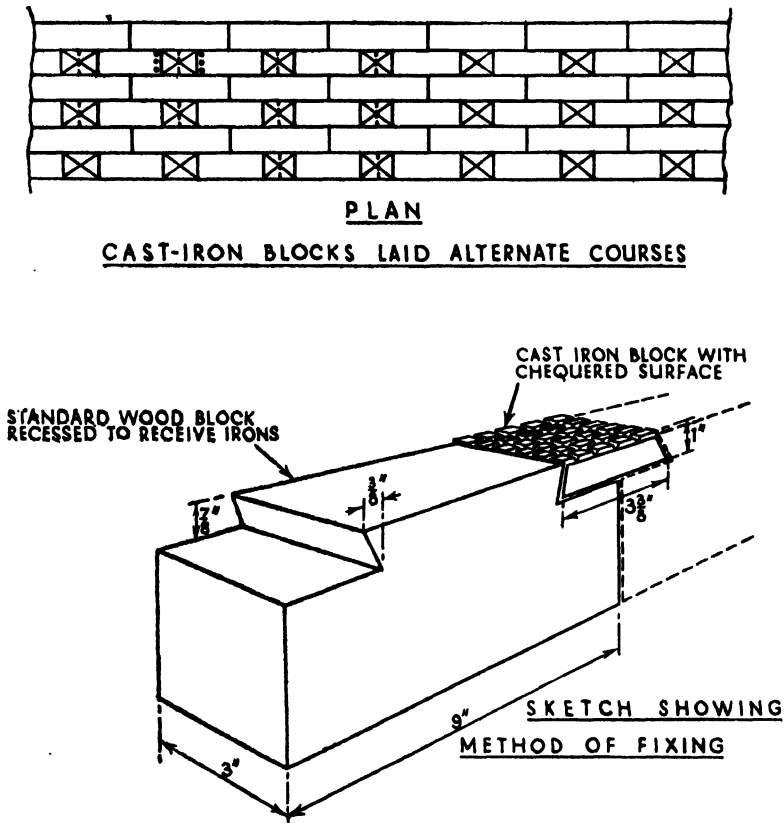
FIG. V.43.—Wood Paving constructed with Short ($4\frac{1}{2}$ in.) Blocks and Wide ($\frac{3}{8}$ in.) Splines.

its stability and adhesion) of a character that will be reasonably plastic in winter and sufficiently but not excessively viscous in summer.

The *life* of a good wood paving might be expected to be 20–30 years or even more under the heaviest modern tyred traffic, and longer under lighter demands. Blocks from various streets, on being taken up in 1927, after having been laid for 13–19 years, showed a loss by wear of $\frac{1}{2}$ in. to 1 in. And blocks laid in Aldwych in 1926 are still in excellent condition, with the minimum of maintenance. But wood

paving, like other road surfaces, has to be carried out with experience in the special technique of production even more than laying, for the best results to be obtained.

Wood blocks used to wear unevenly so that water lay on the surface, which accelerated disintegration and increased impact and vibration ; but to-day, when greater care is taken in the selection of



By the courtesy of A. L. Downey, Esq., Borough Engineer of St. Marylebone.

Fig. V.44.—Non-Skid Cast Iron Blocks for Road Paving.

timber, this is very rare. As described elsewhere, surface dressing, before unevenness begins to occur, will extend the life of the paving in a surprising degree.

With modern traffic the tendency to attrition is less than with horse-drawn iron-shod vehicles, but there is a greater tendency to displacement (push) under power wheels of especially heavy 'buses and lorries ; this is also reduced by surface dressing.

The following Table shows the relative wear of blocks measured with the grain laid vertically, inclined, and horizontally ¹⁴⁰ :

	Amount of Wear.
Fibres vertical	0.125
„ inclined at 70°	0.147
„ „ 60°	0.182
„ „ 45°	0.250
„ „ 30°	0.310
„ „ 15°	0.375
„ horizontal	0.500

A very successful block paving, especially suitable for omnibus stops and similar positions of road strain, consists of an alternation of wood and iron. It was invented by F. W. McCarthy, a former Roads Superintendent of the St. Marylebone Borough Council, in London. It was first laid in Oxford Street in 1939 or just before. Fig. V.44 shows its construction and dimensions. The iron blocks ⁵⁴⁴ are not firmly attached to the wooden base, but are retained in position by the dove-tailing alone ; the chequers are about $\frac{3}{8}$ in. high. The paving is pitch-grouted as usual, the iron blocks being whitewashed beforehand to prevent adhesion of the pitch.

Creosoting. Creosote oil is almost universally employed for impregnating timber for the purpose of preservation, as it approaches more nearly than others to the ideal substance, which should be toxic to fungi, easily penetrative of the wood, and reasonably permanent when in position. The most efficient creosoting oil is Type A of B.S. 144 : 1936 (Amendment, Feb. 1941).

Three processes for the pressure creosoting of timber are recognized in B.S. 913 : 1940. The original *Bethell* process—the Full-Cell process—subjects the wood to a vacuum followed by creosote at a pressure above that of the atmosphere. The *Rueping* process—the Empty-Cell process—which is largely used for wood blocks, subjects the timber to compressed air followed by creosoting at a high pressure. In this, subsequent ‘bleeding’ is less than in the *Bethell* process. The *Boulton* process—Boiling-under-Vacuum—vaporizes the water out of the wood, and therefore is specially applicable to unseasoned wood.

According to the Specification, the minimum absorption of creosote varies between 9 to 14 lb./ft.³ according to the wood, Douglas Fir requiring 9. This has been called into question on the grounds that any exudation of creosote into the surrounding bitumen grout would be seriously harmful to the latter’s function as a waterproofing material ; and that more than 5 lb./ft.³ is unnecessary.

The conditions for such creosoting has been minutely worked out,

ensuring a regular absorption of the creosote into the more- and the less-resistant fibres of the wood.

The origin of this toxicity to fungi is still not fully established, as the neutral components are poisonous to fungi as well as the acidic. It was thought to depend on the solubility to a sufficient degree of the constituents of the creosote in the cells of the fungi, or the poisoning may be mechanical by clogging the processes of the cells from without.

Considering that the cells of the treated wood do not obviously swell, it has been generally assumed that the creosote penetrates the wood through the intra-cellular spaces. Even though the phenols may wet the surface of the wood cell walls ⁴⁰² the complete action of the creosote is not clear.

Laboratory work, such as observation of the rate of attack by fungi on wood impregnated with various liquids under test, shows which creosote is likely to be valuable and which useless; but it is not yet possible to compare the value of different creosotes. Field tests, so far, only can do this, and they take years to carry out. An important reason for this is that so much depends on very widely differing local conditions ⁴³¹. A 9-months' weathering test (in America) has shown that the creosote itself is considerably changed but not sufficiently to fail in its protection of the wood from fungi ⁴⁵⁹.

Foundations. At one time it was the practice to lay concrete to within 1 or 2 in. of the finished surface of the foundation, and then to apply a 'float' of cement and sand to bring it to a fine, smooth surface upon which the blocks were laid.

As a result of frequent failures of wood paving, in consequence of the breaking up of the cement float under modern traffic, it is now the general practice to lay the concrete to its full thickness in one operation. Great care is necessary to ensure an accurate surface, particularly on gradients when there is a tendency for the concrete to flow or settle downhill.

A cross-fall of 1 in 32 to 1 in 48 is usually desirable, and the longitudinal fall of the channels should be not less than 1 in 144.

Laying. It is the invariable practice to lay wood-block paving with the grain vertical. This gives a maximum resistance to wear, the best foothold, prevents splintering at the surface, and holds most effectively applications of grit or surface dressing.

In the old days the blocks were dipped in hot pitch and oil and either laid tight against one another, or with spacing splines $\frac{1}{8}$ in. to $\frac{3}{16}$ in. thick by about 1 in. deep. In the latter event the joints were run with a similar mixture.

It was found in some cases that during hot weather the pitch

melted and found its way under the blocks, causing them to lift and the surface to become irregular. To obviate this some engineers filled the lower part of the joints with cement grout.

It was usual, with either process, to cover the finished paving with crushed shingle— $\frac{1}{4}$ -in. to $\frac{3}{8}$ -in. gauge—which in earlier days was left to be worked in by the traffic but is now rolled in.

The lasting qualities of wood paving in those times undoubtedly depended largely upon the burring over of the edges by steel-tyred traffic and the penetration into joints and blocks of the grit which was frequently applied. The effect of rubber tyres—particularly of



FIG. V.45.—The effect on the Pavement and Kerb of Expansion of Wood Paving, showing also the open condition, after contraction, 6 years after laying, resulting from failure to apply surface dressing.

pneumatic tyres on power-driven wheels—is very different from that of iron-shod horses and steel-tyred wheels.

There are those who contend that expansion joints are unnecessary with modern types of wood paving blocks, but this is not supported by all experience. Roads paved with wood in recent years by firms of repute and long experience have expanded to such an extent that the expansion joints, originally $1\frac{1}{2}$ in. wide, have disappeared and heavy granite kerb laid on and backed with concrete has been displaced and the footpath paving lifted and cracked (Fig. V.45). In some cases damage to the footpath could be prevented only by removing a channel course of blocks, each side of the road, and restoring the expansion joint by cutting the blocks in half.

More recently it has been affirmed that expansion joints are unnecessary if the kerbs are backed by concrete sufficiently strong to withstand the occasional pressure of the road blocks. If an expansion joint is required, it can be produced by tightly packing sand or creosoted sawdust to within 1 in. of the top of the blocks, and filling the rest with bitumen. In this way there is nothing loose to work its way out or under the blocks.

Wood paving has been laid to a gradient of about 1 in 11, but it is inadvisable to lay it at a gradient exceeding about 1 in 15, although the non-skid qualities of the surface may be improved by suitable dressing.

Surface Finishing and Dressing. Without surface dressing, wood paving can be dangerously slippery, therefore the finished surface should be lightly gritted with stone chippings and rolled. Surface dressing of wood paving has been found most valuable, but it is advisable to allow a few months to elapse before applying a dressing to permit surplus creosote to be dissipated.

There has been a tendency by advocates of wood paving to deprecate surface dressing, apparently because it is thought to cast some reflection upon this class of paving, but contractors responsible for maintenance have adopted the practice. (See Fig. V.45 for the result of omitting to surface dress wood blocks.)

To-day bituminous emulsions are extensively used. They should have a bitumen content of 55 per cent., and be applied 6-7 yd./gal., and blinded with $\frac{1}{4}$ -in. granite or slag chippings.

Asphalt carpet coats for wood can be of considerable value, but they should not be applied if the wood-block surface is seriously deteriorated.

Before the advent of surface dressing, careful selection of the timber was of great importance, mainly with a view to preventing uneven wear, which was the principal cause of disintegration. To-day, timbers of a lower grade can be used where systematic and effective surface dressing is provided.

Another serious defect of wood paving was the tendency to lift during wet weather, particularly after a dry spell, an evil which may be assisted by the rubber tyres of the driving wheels of vehicles. It was not uncommon for a hump to be thrown up, 6 in. or more above the road surface, and as this happened very quickly it was liable to be a source of danger to vehicles, in addition to increasing the cost of maintenance. This trouble has also been largely eliminated by the use of improved forms of blocks, which—in conjunction with surface dressing and grout between the blocks—enable the paving to be rendered impervious.

Sometimes special provision has been made, in a reconstructed road, for under-draining the wood-block paving to prevent this lifting of the blocks by water, but modern materials and methods should render this unnecessary.

One case within the experience of the Authors is sufficient to show the value of surface dressing. A Class I road in Wandsworth, wood-paved on concrete foundation, carrying traffic of the order of 21,000 tons per day and including a frequent service of 'buses and a substantial proportion of other heavy traffic, had begun to disintegrate after being down about 11 years and was apparently approaching the end of its useful life. In ordinary circumstances it would have required relaying within a year, but by surface dressing and repeating the process every alternate year, its life has already been extended for nearly 20 years.

Specifications. There is no standard specification for block paving, but individual firms have their own carefully worked out requirements. Comparing the later practice with the earlier, it should be noted that the creosote has been standardized by the B.S.I.; that hand-dipping of the blocks is obsolete; that shingling with $\frac{3}{8}$ -in. pea grit is being abandoned in favour of $\frac{1}{4}$ -in. steel slag or granite chippings.

BRICK PAVING

(See also ³⁰⁷)

The success during many years of brick paving in America and Holland, led to an effort in 1923, to popularize it in this country, the first brick road being laid in Sherlock Street, Birmingham, in 1922. It was established that suitable clay was to be found all over England, that manufacturers were able to produce an excellent brick, that a testing machine (the Rattler) had been developed that gave trustworthy results as to the nature of the brick; and all was ready for the new industry.

Blame that it did not develop was put upon the lack of interest of the local highway authorities, and on the spasmodic energies of the manufacturer. With considerable difficulty about half a dozen trial stretches were laid, to be followed later by a few more; and when proper control had been exercised success was reported after a number of years.

An impetus was given to brick paving by the favourable resolutions passed by the International Road Congress, at Washington, 1930; and as a result the Himley Brick Co., Ltd., made a show at the British Industries Fair at Birmingham in 1932, which led to an active interest being taken in it. To-day, brick paving is dead in this country, but in Holland it is as popular as ever. New methods have enabled it to

compete with other forms of construction : by setting the bricks in mortar, stabilizing the soil with cement, and using larger bricks.

The *qualities* claimed on behalf of brick roads may be summarized as follows : impermeability ; durability, up to 20 years, after which many bricks can be relaid reversed ; non-skid to motors and horses ; very low tractive force required ; suitable for all traffic and all gradients ; practically noiseless ; easily cleaned ; give no dust or mud ; easy to repair or re-instate, especially when grouted with asphalt in place of cement ; very cheap to maintain ; can be laid with a very low camber ; uninfluenced by climate ; when properly made has a minimum water absorption ; slight and uniform wear.

The *brick* is of standard dimensions, $9 \times 4\frac{1}{2} \times 3$ in., and is without spacing projection or panel. It is best wire cut, as a pressed brick is liable to lamination and flaking. Bricks for a particular job must be of the same quality, otherwise excessive unevenness may result. A brick pavement must be *laid* on a sound foundation, but the details depend on local requirements.

Specifications have been drawn up for the laying of the Brick Paved Road, and for the Bituminous Grout, by the British Paving Brick Association ; but there is none for the paving brick itself. Therefore, the American Rattler test has been unofficially adopted ³⁰⁸.

Development of brick paving has continued in Holland and America. An interesting continental development has been a sand-lime brick, impregnated with about 10 per cent. of bitumen ⁴⁵⁷. At the present time there seems little chance of brick paving being revived in this country.

SETTS

The type of non-slip felspathic granite, suitable for setts, has been referred to under the general desirable characteristics of granite for road-stone. In addition, a rock of uniform grain is to be preferred to a porphyry in which crystals up to 3.5 mm. are set in a matrix of fine material ; and to one that contains much hornblende and mica. The setts themselves should be of uniform dimensions and free from pronounced irregularities ¹⁵⁸.

Setts, like road bricks, were usually laid on a bedding of sand, in spite of the adverse opinion entertained for this type of bedding ¹⁴⁴ ; the following are the main objections :

1. It is very difficult to lay a bed of equal density.
2. There is a tendency for the sand to rise between the blocks and so prevent the complete entry of the grout.
3. There is liability of unequal moisture content ; and to displacement of the setts when water enters the road bed.

4. There is liability of leakage of the sand through cracks and disappearance into manholes, sewers, etc.

To-day setts are generally laid on a weak mixture of cement and sand, slightly damp, which gives a more stable bedding than sand alone.

Modern sett paving shows a great improvement over the old, in the quality of the stone, the accuracy of shaping, and the length of life of the paving as a whole. The setts are carefully squared and laid with close joints (to $\frac{3}{8}$ in.), and the surface is finely dressed. For long they were jointed with a hot bituminous mixture in place of the old tar and oil mixture : the bitumen was of 50–60 pen. with 50–60 per cent. fine mineral matter. To-day there is increasing use of cement grouting, which unites with the cement bedding and so prevents rocking. The result is a paving with a clean even surface, having a very long life especially under rubber-tyred traffic, low maintenance costs, comparative quiet (except under horse traffic) and freedom from dust. It is relatively high in first cost but not expensive when length of life is considered.

British Standards 435 : 1931 and 706 : 1936 regulate the sizes and character of the granite, whinstone, and sandstone setts.

It has been found in Sweden that the amount of wear per year is proportional to the traffic intensity and that the effect of climate was negligible. Wear was about 0.09 mm. a year under 1,000 vehicles a day, and that there was greater wear at the edges than at the centre of the block ³⁸⁵ (p. 253).

A method of using granite setts as kerbing has been devised (Fig. V.46) ³⁶¹.

An examination of the technology of sett pavements has been made in Sweden ⁴⁹², which paid particular attention to joint fillers. Sand fillers between the blocks is convenient and cheap, and dust can be prevented from spreading by calcium chloride. Bituminous mixtures are preferable as giving better durability and evenness over a long time, but they may become unsightly and lower safety by the possibility of skidding. Emulsions are less successful. Cement mortar leads to even wear, but subsequent adjustments cannot easily be made.

RUBBER PAVEMENT

The resilience of rubber gave early hope of a road surface that would absorb shocks and vibration, and incidentally lessen noise. This may be considered to have been achieved, but the great hindrance to wide adoption is the cost. A recent consideration of the position which these roads might take has been given by C. Ridley ⁵⁶⁷.

In 1870, rubber slabs, 2 in. thick, were laid in the entrance of St. Pancras Station, London ; and after repairs in 1891, 1908 and 1915 some of the original slabs were still in position in 1934. The courtyard of the Savoy Hotel was covered with rubber from 1904 to 1911. It gave trouble in wet weather from rain penetrating beneath it, but there is no record of extensive repairs.

In 1915 Rubber Roadways, Ltd., started the difficult and arduous work of experimenting and developing rubber for road surfacing, and this has continued mainly in their hands. The material was obtained by the exchange of a fixed percentage of the output of the plantations for shares in the Company.

A close examination of *rubber-bitumen* mixtures was made about 1937 and onwards, by the Rubber Foundation in Amsterdam and others ⁵⁶³. The addition of rubber to bitumen raises the hardness, softening point, viscosity, and elasticity of the bitumen ; and reduces any tendency to polishing (by giving a sand-paper surface) and to waviness. The underlying theory of such amalgamation is that the rubber dissolves in the oily component of the bitumen. Earlier and empirically, a road surface was made by dissolving rubber in a flux oil and using this to mix with the bitumen, and a successful trial was made with it ⁵⁶¹. Such a mixture was laid on a water-bound tar-sprayed road to a thickness of $\frac{3}{4}$ in. and consolidated with a light roller to $\frac{1}{2}$ in. ⁵⁶².

Some sections of a rubber-bitumen road, laid in Bournemouth in 1937, are still in existence.

Rubber-asphalt has been closely studied by J. A. Plaizier in a paper described as 'stimulating' ⁵⁶⁴.

A mixture of rubber with cement, bitumen, and chippings gave the 'rubber asphalt' that is said to have lasted for well over 10 years in the South of France. A mixture of rubber with petroleum, bitumen, and Portland cement has been reported from the Straits Settlements and Singapore. A thin non-skid sealing coat was tried.

Investigations have also been made on *rubber-tar* mixtures ⁵⁶⁵, but nothing has been heard of successful practical application. They show a general physical-chemical similarity to tar-bitumen mixtures.

In the same way that the first coaches of the newfangled railway were in close imitation of the stage coaches of the road, so the first attempt to use rubber as a road surfacing were in imitation of wood *blocks*. These have been, and are being, continuously improved, and by now it is mainly the price that hampers extension of their use.

Rubber blocks were developed ; the usual type consisting of a rubber surface fixed to a block of, for instance, a mixture of rubber,

filler, and cement, or of concrete, or an ebonite base. A difficulty was the wear between the rubber facing and its support, not wear under traffic. This has been overcome ⁵²⁹.

The types of blocks that have been tried are summarized (to 1932) in the Table on page 250. They are all laid on concrete, with small variations as to details of method.

The Gaisman blocks were first laid in New Bridge Street, London, in 1926. The rubber wearing surface was not manufactured to its full thickness, so that it had to be made up of three separate thicknesses fixed together. There resulted a considerable amount of detachment in strips, which has reflected badly on the reputation of the block.

Since that date, the Gaisman block has developed into a prominent representative of its class ⁵⁶⁶. A late form which has been laid in Duke Street, London, is grooved like the asphalt road tiles of earlier date. These were developed to minimize skidding from two causes: they were given a matt surface to avoid the psychological effect of driving on a shiny surface which looked wet; and they were given sharp arisises to avoid actual slipperiness.

Different methods of construction and various processes have been tried (see also ⁴⁴⁴), but the Gaisman block, 9 in. \times 4½ in., has predominated. From 1935 to 1940, when the Rubber Control stopped the use of rubber for roads, several thousands of square yards were laid, including one of special anti-skid design. Apart from incidental difficulties, rubber paving can be considered as having a long life.

One of the troubles associated with the laying of separate blocks was their 'travel' under traffic. Diagonal laying and a jointing of bitumen constitutes an experiment by the Leyland Urban District Council.

Concentrated and stabilized rubber *latex* can be exported from the rubber-growing countries without suffering decomposition; and it is now being tried for road purposes without being manufactured into rubber as commonly met with.

Rubber Latex Surfacing. This interesting experiment ¹⁸⁷ consisted of a mixture of a latex compound, Ciment Fendu, and inert fillers, such as sand, slate powder, or the like. (See also ⁴⁰⁴.)

A stretch containing about 30 per cent. of rubber, partly protected from the weather, was laid to carry heavy vehicular traffic into a railway station. Further experience showed that surfaces with as low as 13 per cent. rubber still retained the resilient characteristics associated with rubber.

(See also ³⁴⁴, under *Emulsions*.)

Name of Block.	Nature.	Dimensions. in.	Locality.	Date Laid.	Area. sq. yds.	Traffic.	Remarks.
Leyland . . .	Very hard base, graduating to $\frac{1}{2}$ -in. soft cap.	$8 \times 4 \times 3$	Fresh Wharf, behind Adelaide House, London.	1924	400	—	T-irons to prevent movement. Overlap for interlock.
Cowper . . .	Three layers, middle hard composition, top and bottom softer and tougher.	$2 (9 \times 4\frac{1}{2}) \times 2\frac{1}{2}$	Thurloe Place, South Kensington, London.	1928	300	240 tons per yd. per hr.	
North British .	$\frac{3}{4}$ -in. rubber cap fixed by steel lugs on to concrete base.	$9 \times 4\frac{1}{2} \times 1\frac{1}{2}$	Blackfriars (improved block). Shadwell Place, Edinburgh.	1923	220	Medium fast.	Grouting between bases.
Cresson (Dutch)	Rubber cap vulcanized to composite base (chippings, sand, rubber latex).	$9 \times 3 \times 3\frac{1}{2}$	Buchanan Street, Glasgow. Craydon Road, Anerley.	1923 1928	50 150	Particularly heavy. Between kerbing and tram lines.	—
Gaisman . . .	$\frac{3}{8}$ -in. rubber cap, vulcanized on to vitrified brick base.	$10\frac{3}{8} \times 8\frac{3}{8} \times 4\frac{1}{2}$	New Bridge Street, London. Market Street, Newcastle.	1926 1929	700 991	280 tons per yd. per hr.	—
"	Untearable black rubber tread.	$9 \times 4\frac{1}{2} \times 3\frac{1}{2}$	Buchanan Street, Glasgow. Victoria Street, Bristol.	1929 1930	992 278	—	—
" (Improved)			New Bridge Street, London. Market Street, Huddersfield.	1932 1932	200 1,264	—	—
Dunlop's new Type	Rubber case to be filled with concrete.	$9 \times 12 \times 6$	Local Trials.	1932	—	—	—

Rubber-Asphalt Surfacing.

Many lines of investigation into the nature and properties of mixtures of rubber (dried latex powder has been suggested ⁴⁴⁶) with asphaltic bitumen, and filler or broken stone ⁴⁰ have been going on for years, but by now nothing of importance has resulted and interest seems to have lapsed. An early trial ¹⁸⁹ consisted of a mixture, made cold, of shredded old rubber tyres (with the fabric) with Trinidad asphalt, a little raw rubber and vulcanizing mixture, and limestone filler. This mixture was cast into slabs. A concrete foundation was painted with bitumen; and the blocks were surface-fused with a touch of a blow-lamp, and laid in place. Adhesion with the concrete was found to be very firm. The cost was a fraction of that of rubber-block paving. It formed a vibration-absorbing base when laid between the foundation and the road surfacing selected. When compared with, say, $4\frac{1}{2}$ -in. wood block, which absorbs 12.3 per cent. of vibration, the best mixture of this new material absorbed 83.5–93.5 per cent. according as the thickness of the material was varied from $\frac{1}{4}$ to $\frac{3}{4}$ in.

[These figures are to be taken as being comparative and not absolute.] ¹⁸⁸

So far as experience has been obtained, the reduction of street noise by rubber paving has been very marked, and the diminution of vibration has been 30 per cent. in Whitehall, and 40–50 per cent. in New Bridge Street. The coefficient of friction of rubber to rubber (dry) ³⁹ is 0.693, appreciably higher than that of rubber on other surfaces. Such slipperiness as there may be is lessened by some form of surface ribbing, and here, again, one meets the same flat contradiction in opinion as regards slipperiness of rubber as is met with in the case of concrete.

The general *trend* of development of rubber roads is being actively extended in several directions, but there is little that is useful for these pages.

The main drawback to the use of rubber surfacing is the first cost, though length of life and minimum or absence of maintenance may offset this to some degree. The solution, which is one of chemical technology and not a road matter, may be found in laboratory research on synthetic rubber.

MISCELLANEOUS

Silicated Surfaces.

A hardening and waterproofing treatment of concrete and of limestone roads has been developed, depending on the use of a special

grade of sodium silicate, containing a higher proportion of silica than is usually present in water-glass ⁹⁹. The course of the chemical changes ^{120, 122, 199, 306}, that occur when concrete sets and hardens have been described in that connection as well as the silicate treatment of concrete (page 251). When binding limestone it is closely similar, the first stage being the formation of hydrated sodium carbonate and amorphous silica. The matter is further complicated by the continuous action of atmospheric carbon dioxide liberating silica ³⁰⁹. Even soft stone can be converted into a hard surfacing.

The first limestone-silicate road was laid in Leeds about 1908 ; and its use extended in 1918, and later in Switzerland, France, and Central Europe. A little has been laid in Ireland. This method of road construction has not been widely adopted in this country, but full information is available ²⁷⁷. According to Swiss experience, ice adheres more strongly to, and lasts longer on, silicated than with other road surfacings, so that its use in the coldest parts of this country should be carefully considered.

Flag Stones.

These are usually of sandstone ; sufficient mica should be present to assist dressing, but not enough to cause excessive flaking under foot traffic. (See also ¹⁵⁷.)

(See also *Pre-cast Stone and Concrete*.)

Pre-Cast Stone.

There is great activity in the manufacture of pre-cast products for road construction, on account of the ability to utilize natural products in a controllable and adaptable form. All such moulded products must be cured in the usual way.

Kerbs, flags, paving slabs, etc., are being produced in considerable quantities ; and although concrete kerbs are not as strong as granite kerbs, this disadvantage is diminishing in importance with the gradual disappearance of iron-tyred traffic.

Moulded concrete kerbs, channels, and quadrants are controlled by the British Standard Specification 340 : 1936. The tests of the kerbs and channels are limited to transverse strength and absorption of water.

Kerbs, Channels, Quadrants, and Setts.

These, manufactured from granite and whinstone, have been standardized by B.S. 435 : 1931 ; and from sandstone by B.S. 706 : 1936.

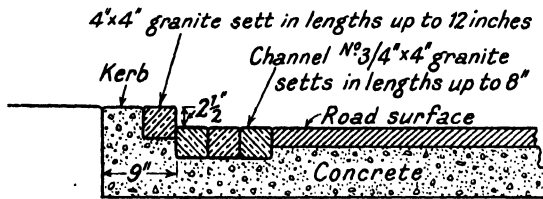
The latter are cheaper than those of granite ²⁵⁵ ; they are also less slippery, but do not last so long.

Limestone is sometimes used.

The use of *British granite* for kerbing has always been restricted by a variety of causes. The chief of these has been the competition of Norway and Sweden (and in some degree Belgium) which can supply excellent kerb at prices that are uneconomical to the British producer. This has been possible through the character of the rock in those countries being exceptionally suitable. It cleaves in a manner which enables production to take place with a minimum of labour and in long lengths. It is usually so situated that it can be loaded into sea-going ships with little trouble and expense. Moreover, it is often conveyed as ballast in coal ships returning to Britain, thereby reducing the cost of both coal and kerb.

India also has an excellent kerb granite in Mysore.

At the same time, only a few British quarries possess the most suitable stone for kerb production. Most of the stone available requires more dressing and kerb can be made in only short lengths. Transport over land is expensive. At one time and in some districts,



By the courtesy of the Cleve Hill Quarries.

FIG. V.46.—Suggested Use of Setts for constructing Kerb and Channel, when longer granite lengths are not available.

the masons insisted that kerb production must be confined to them ; and as their most profitable work was in preparing block granite for buildings, they would not produce kerb when building masonry was required. The result was that the supply of kerb was erratic and unreliable from those areas.

Some years before the First World War, the Government endeavoured to assist the industry. Later the B.S. 435 : 1931, standardized a limited number of dressings and sizes ; and—what should have been of the greatest value to the industry—highway engineers agreed to a substantial reduction in their demands as to lengths. Further, a Joint Committee of users and suppliers was set up under the auspices of the Ministry of Transport to regulate the supply and prices for the London area. Interest was sustained by inter-quarry competitions in road-drilling and kerb dressing.

As a result of this encouragement, followed by drastic Government economies, very considerable stocks of British granite accumulated. All efforts, however, came to an end on the outbreak of the later war.

To-day, conditions are again much the same. War has stopped importation of granite kerb even from Northern Ireland and the Channel Islands. Arrears of work have accumulated, and a scheme has been started to attract ex-Service men to the industry. The shortage of kerb has led to the use once more of setts along country roads (Fig. V.46) ³⁶¹.

Silicosis.

It must be noted that all stone that gives off fine siliceous dust, when worked is liable to injure the lungs of the workers. This matter has had very serious attention from the Home Office since 1924, and studies and Reports have been published.

PART VI

ACCESSORIES

Manhole Covers.

Most of the larger covers are over sewer manholes and fortunately, in the majority of cases, these are under the same control as the roads.

Smaller covers such as hydrant boxes and syphon boxes often belong to other bodies. Covers to telephone and electricity manholes are generally on the footpath, where they are less likely to cause trouble. Covers liable to frequent or prolonged use, such as to electric light and telephone boxes, should not be permitted in the carriageway unless this is unavoidable.

The most serious cause of trouble from road covers arises from the fact that their wear is slight compared with that of the surrounding road material, and consequently in course of time they are left projecting above the road surface. Materials such as tarmacadam, which are liable to compression after laying, should be laid slightly 'proud' of covers with the intention that it should become compressed to a uniform level. It is now seldom necessary to provide an apron of setts, as was done in the days of water-bound macadam.

The stability of the manhole cover is secured, in some cases, by that portion of the frame which is below the road surface being provided with vertical fins, big or small or both, straight or curved, between which the road material becomes firmly embedded.

Manhole covers should be of the non-rocking type, of which there are many well-known patterns on the market, such as those with three-point seatings, rubber seatings, renewable sand seatings, or sloping sides. The surface should have a non-skid finish, which is secured by complicated raised pattern, or by inset of wood or granite blocks.

Cast iron is the material usually employed for road covers, but special semi-steel grades of metal, which are less liable to break, are favoured.

Road Gullies.

Road gullies should be of ample capacity, particularly on gradients. The spacing should be carefully considered, having regard to width of

road, gradients, position of side roads, type and size of gullies, and character of locality. Where there is risk of obstruction by leaves, etc., kerb overflows should be provided.

Under ordinary conditions one of the most satisfactory types is the common glazed ware pot gulley 1 ft. 6 in. diameter and 4 ft. deep with a water capacity of 30 gals. The special advantages of this type of gulley are that it is provided with a deep seal, that it has ample capacity for silt below the outlet, and that it is easy to clean it thoroughly—particularly the circular form—by means of a mechanical vacuum gulley emptier. It is also convenient to fix, and is comparatively inexpensive.

The usual practice is to set the pot in concrete and to surround the outlet with this material. One or more courses of brickwork set in cement are generally provided to carry the grating frame.

There are many more elaborate designs upon the market, but most of them are expensive and contain features seldom necessary. For instance, some are provided with special eyes to enable the connection with the sewer to be cleared, but with a properly designed gulley and satisfactory connection the risk of blockage of the latter is found to be very remote.

Gulley gratings are usually of cast-iron, but self-seating all-steel gratings are much stronger. A grating has been designed with the bars set at an angle and is useful on gradients.

Cast Manhole Covers, Road Gulley Gratings and Frames, are the subject of B.S. 497: 1945.

In agricultural areas the free movement of cattle has sometimes to be restricted without hindering normal traffic. This is done by means of a **cattle grid**, an area of iron rods, spaced $3\frac{1}{2}$ in. over a shallow pit, which discourages the passage of cattle but is of no hindrance to motors. There is provided a gated by-pass for cattle in charge of a man and for horse vehicles; the success of this arrangement depends on the careful closing of the gate after use.

PART VII

PLANT

(other than that already described in their particular sections).

Great Britain is well served with firms that produce first-class plant for road construction of all types (except, perhaps, mix-in-place, which is not practised here) on a big or small scale. Great ingenuity has been developed, and this has been backed by the best engineering practice and materials. Improvements are continuous.

Some firms specialize in the hiring of roadmaking plant to road authorities and contractors.

Rolling and Rollers.

The object of rolling is the production, so far as is practicable, of a regular consolidation of loose road material of any type from sub-soil to carpet, without waves or the potential possibility of subsequent wave formation or corrugations (q.v.). The responsibility for this evenness rests both with the machine and the man controlling it.

The first steam roller (developed from experience of heavy traction engines) was made by Aveling and Porter in 1863, when it was tried out in Hyde Park, London. It weighed 20 tons, and exerted a pressure of 3 tons/sq. ft. ; it was still in fact a very heavy traction engine. The first true road roller was designed in 1867 and was subsequently sold to Liverpool. It weighed 30 tons ; the driving rolls were 7 ft. in diameter and the steering roll 5 ft., and it could turn in its own length. Two years later others of the same pattern went to America, and development of rolling proceeded rapidly.

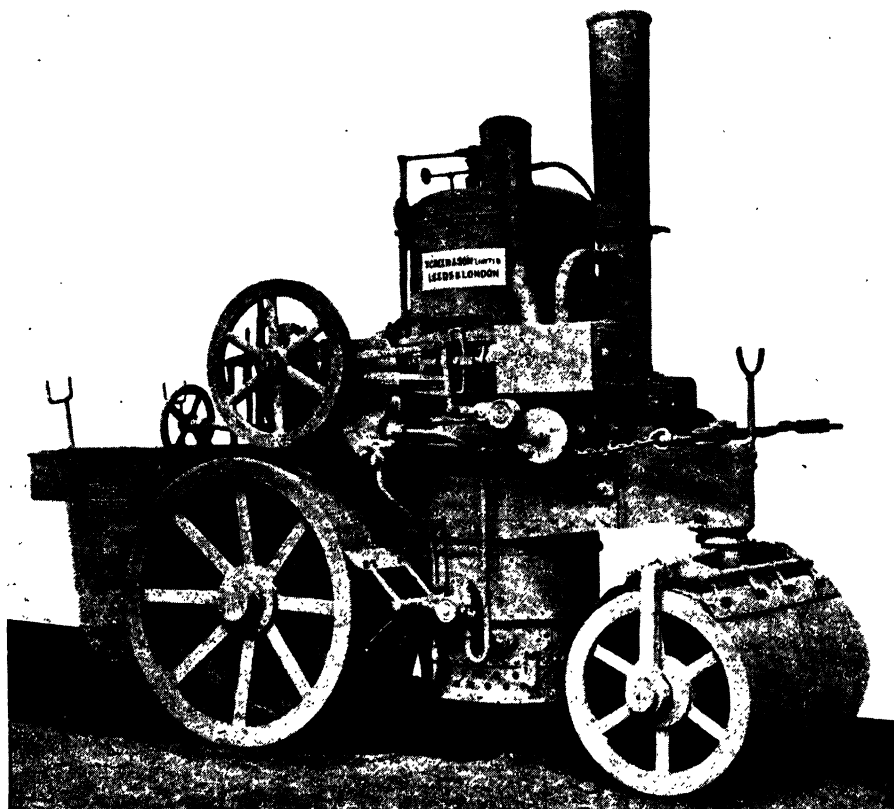
In 1874 a steam roller, constructed by Green of Leeds, was supplied to Queen Victoria for service in the Royal Gardens at Windsor (Fig. VII.1). Development since has been phenomenal.

Two *types of rollers* are available—the tandem and the 3-roll machines ; and the choice often depends mainly on the personal preference of the Surveyor, as each type has certain advantages and disadvantages.

The *Tandem Roller* has a more even distribution of weight on the two rolls. This even distribution and the quick reverse that is possible

lead to a very smooth finish to the road surface, without marks or ridges, and is, therefore, very suitable for the consolidation of hot sand carpet and the like. As a rule, the overall width is less, which is advantageous in certain cases.

It is, however, subject to side-roll, and may have difficulty in mounting hills, owing to insufficient weight on the single wide back driving roll.



By the courtesy of Messrs. Thomas Green & Son, Ltd.

FIG. VII.1.—Steam Roller manufactured for Queen Victoria in 1874.

The *Three-Roll type* is usually preferred as being of greater general use for the consolidation of subsoil and foundations, as well as surfacings, and even of sand carpet if the hind rolls are wide enough to give a good overlap (usually about 3 in.) on the tracks of the front roll. The existence of two back rolls enables the back axle to be adapted to the camber of the road.

A type of roller that has been designed to deal drastically with

surface irregularities is the three-roll roller, in which the central roll can transmit most of the total weight of the roller to the road surface.

The Arnold roller had three rollers of equal size. The earlier Crompton roller tempered the action of the central roll by mounting it on springs. And there was the Aveling-Barford, in which the central roll is much smaller in diameter and is brought into action hydraulically. Similar in appearance and action is the Marshall roller, of which published figures show that road surface irregularities can be given a pressure of up to 82 per cent. of the total weight of the roller.

This type of roller had a vogue before this last war, but it has somewhat lost its position in favour of careful spreading of aggregate



By the courtesy of Messrs. Marshall Sons & Co., Ltd.

FIG. VII.2.—Diesel Roller with Surface Levelling Attachment.

before rolling. Greater pressures, fore and aft, are obtained in the 6- and 13-ton Aveling-Barford rollers, by means of a sliding ballast weight. But it does still exist (Fig. VII.2).

A somewhat specialized form is the 'clearside' roller, which enables consolidation to be carried right up to the kerb or wall. Such rollers weight 25 cwt. to 4 tons and are driven by Diesel engines at 2 to 4 m.p.h. For an example of a footpath roller ⁷⁹, requiring 13 b.h.p., see Fig. VII.3.

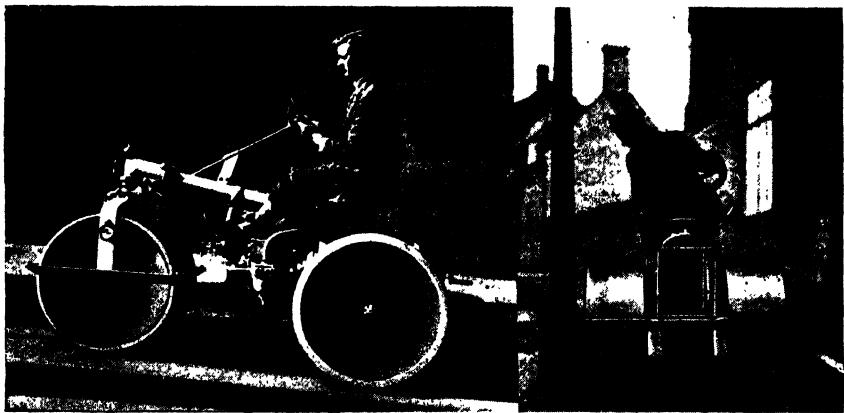
Another specialized roller, for use after gritting a tar-sprayed surface, is one of approximately 4½ tons, consisting of a single roll, divided into a number of contiguous sections, each of which is free to rise vertically. It is drawn by a tractor.

Consolidation. This primarily depends on the weight carried on

the rolls as resulting from the design of the roller, and finally, on the weight transmitted to the road surface per inch width of contact. Approximate figures for normal rollers given in the following Table have been courteously supplied.

CONSOLIDATION		
	Front Roll.	Hind Roll(s).
	Proportion of Weight Carried	
3-Roll	0.33	0.66
Tandem	0.5	0.5
	Consolidating Effect	
3-Roll	1	3
Tandem	1	1.5

Care must be taken in the interpretation of these figures, partly because special rolls are not infrequently required to be fitted, and, partly, because contact is actually never along a line but along a strip of the road surface. The width of this strip and, therefore, the pressure per square inch of road surface depends on the distance the roll



By the courtesy of Messrs. John Allen & Sons (Oxford), Ltd.
FIG. VII.3.—Light Roller, showing neat clearance.

sinks into the initially soft surface. The harder the surface becomes, the less is the sinkage of the roll, the narrower becomes the width of contact and the higher the pressure per square inch ; which is what is required.

Experience shows that if greater weight is put upon the front roll, there is a tendency to push loose material rather than to mount it. Consolidation is not proportional to the weight of the roller.

The *Horse Power* and *Fuel Consumption* for various types and weights of rollers are given, as approximate figures, in the following Table.

HORSE POWER AND FUEL CONSUMPTION OF ROAD ROLLERS (approximate)

B.H.P.				Fuel, etc., per 8-hour day.		
Nominal. tons.	Steam.	Diesel.		Coal. cwt.	Water. gals.	Diesel Oil. gals.
		A make.	B make.			
4 . .	—	10	—	—	—	—
6 . .	18	22	12-14	2	200	1½
8 . .	25	22	16-18	—	—	—
10 . .	25	33	20-23	—	—	—
12 . .	30	33	25-29	2½	240	3
	24	—	—	—	—	—
14 . .	30	—	25-29	2½ 3	140-150*	—
16 . .	35	—	—	3½	350	—

* It is not certain, from the figures available, whether they refer to steam compound engines or not ; those in this line certainly do so.

The most vulnerable part of the roller is the *rolls*, which wear, or may crack or break. Special methods of repair have been devised to prolong their life.

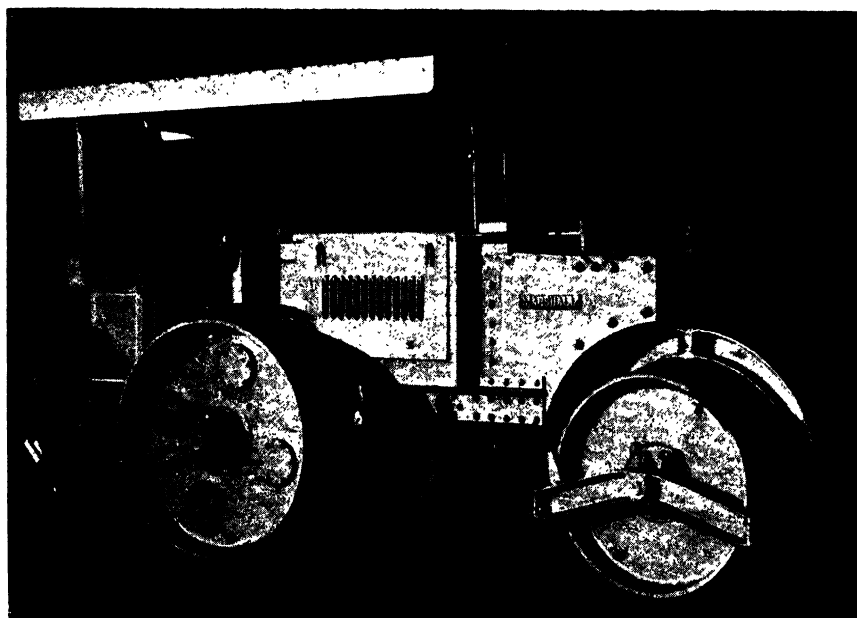
Hand Rollers. Hand rollers, of 3-10 cwt., are used for finishing mastic, etc., and are available with, and without, water ballast which increases the weight by about 2-8 cwt. Still larger sizes of the same type are motor driven, 12 cwt. by a 2 h.p. petrol motor, and 16 cwt. by a 3½ h.p.

Internally heated rollers carry a furnace slung from the axle inside the drum ; they weigh from 4 to 16 cwt.

Crimping rollers, for indenting tarmacadam, mastic, and concrete surfaces, have a negligible compression effect.

Steam Rollers. Steam rollers range from 6-20 tons, those most commonly in use being 8 to 12 tons (nominal). It must be remembered that a roller of a nominal tonnage may be 1-2 tons heavier than the nominal tonnage when ready for the road. They travel from about 1½ to 2½ m.p.h. In certain cases, traction engines can be converted into rollers, and these usually range about 10-15 tons, and vice versa.

Motor Rollers. These were first manufactured by Messrs. Barford & Perkins (so it is claimed) in 1904, but they came into prominence about 1922 onwards.



By the courtesy of Messrs. Marshall Sons & Co., Ltd.

FIG. VII.4.—Diesel Roller.



By the courtesy of Messrs. Chittenden & Simmons, Ltd.

FIG. VII.5.—The Sparkes-Chittenden Roller.

The lighter rollers, of 32–45 cwt., run with a petrol motor of about 9 h.p. up to 3 m.p.h.; from $1\frac{3}{4}$ to 4 tons on petrol with a 12–17 h.p. motor, at speeds of $1\frac{1}{4}$ – $4\frac{1}{2}$ m.p.h. The heavier types, of 3–15 tons, run on Diesel oil (and sometimes on crude oil) with Diesel motors of 9–35 h.p., at speeds of 1– $4\frac{1}{2}$ m.p.h. The motor of a 7–10 ton type of roller is stated to develop 30 h.p. on petrol and 25 h.p. on paraffin, and an 8–12 ton roller motor 40 h.p. on petrol and 32 h.p. on paraffin. Electric starting gear is used; and a fluid drive coupling can be fitted.

The above figures should be taken as being of only general significance, they are continually being improved.

A general view of a modern Diesel roller is shown in Fig. VII.4.

A novel roller—the Sparkes-Chittenden roller—consists in the weight of a lorry acting through its back wheels on a pair of rollers in contact with the surface to be levelled (Fig. VII.5). When loaded with an empty 5-ton lorry, the rolling is roughly equivalent to that of a 4–5 ton roller.

It was designed in 1943, to make up for deficiency in supply to meet a big demand.

The latest development in road rollers is that in which vibration takes place during compression; and the results are claimed to be phenomenal. The vibration has been isolated from the main structure so that the driver is not affected. Little information is available, but see ⁵⁸⁹.

The selection of a motor or steam roller depends on local conditions of supply and storage of fuel and water.

In the past, doubt as to the desirability of motor rollers was expressed on account of the fear that irregular movement and jerky starting might give rise to waves in bituminous surfacings; but experience has led to their increased popularity.

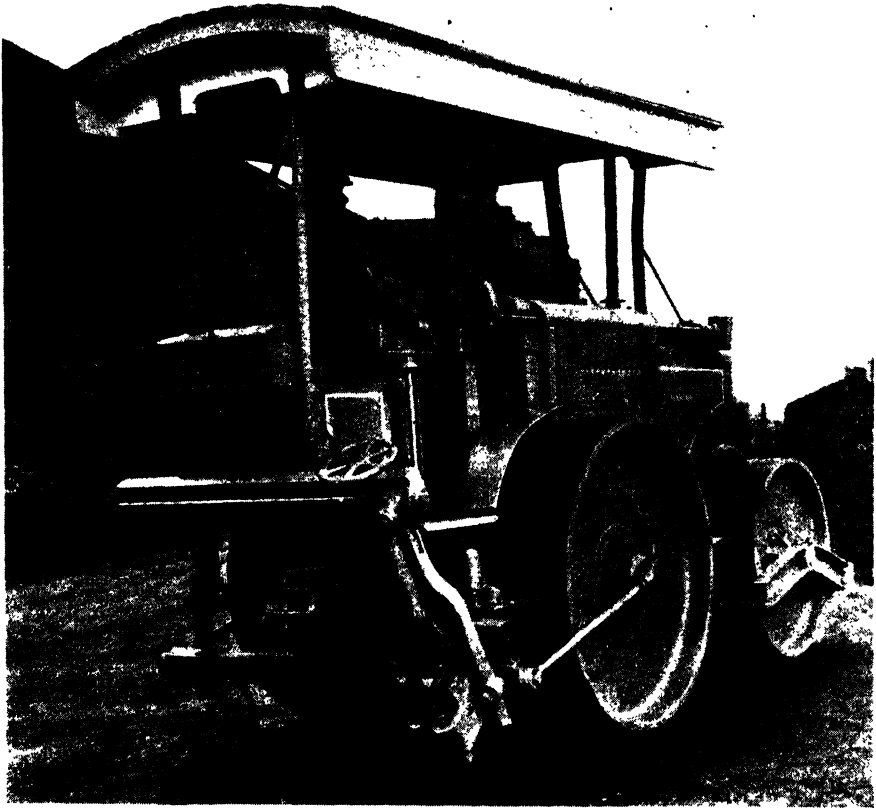
The main advantages claimed for Diesel over steam rollers is their instant availability, economy of fuel, and absence of water requirements and boiler troubles.

Scarifiers.

The breaking of a macadam road surface requires considerable power, and for this reason and because scarifying is so closely connected with subsequent rolling, these two operations are closely associated mechanically.

The scarifier usually consists of a holder, containing 2 tines for an 8–10 ton roller and 3 tines for 10 tons and over, which is attached to the back or back axle of the roller. The tines are of preferably special steel, usually pointed at each end. They are either straight or curved, and are adjustable as regards their depth of working. Spring absorbers

are provided in some cases with the object of preventing shock and damage to the roller, but there is a difference of opinion as to their desirability. In any case it is important that the fire box (where this is used for the attachment) should be specially strengthened to withstand the heavy stresses arising during the working of the scarifier. In some cases the scarifier is designed so as to operate during both



By the courtesy of Messrs. Marshall Sons & Co., Ltd.

FIG. VII.6.—Diesel Roller with Sliding Scarifier.

the forward and backward travel of the roller, but it is doubtful whether this is fully satisfactory. A valuable improvement is the sliding scarifier, see in Fig. VII.6.

Independent 3-wheel scarifiers are also supplied. These are hauled by the roller by means of a rope or chain provided with a spring draw bracket. A 3-tine scarifier, for use with a 10–12 ton roller, has been constructed with independent steering, so that it may vary somewhat

its position relatively to the roller towing it, and so minimize its travel over disturbed material. This type of machine is effective but imposes greater strain, and is less convenient than those attached to the roller ; but it has the advantage of being interchangeable, and of being capable of operation in both directions. To-day, they are no longer manufactured, so far as is known.

Indenters, Crimpers, and Key Cutters are no longer manufactured.

Tampers.

Mechanical tamping can be carried out by means of the internal combustion engine. A rammer has been designed for consolidating the earth in a trench and for settling setts, etc. The machine illustrated (Fig. V.23, p. 182) gives about 80 blows a minute of 2-16 in. fall, and weighs about 215 lb.

A machine more suited to road repairs is also available : a plate $15 \times 4\frac{1}{2}$ in. delivers 400-500 blows a minute of controllable force ²⁵¹.

Wagons.

The road industry is well catered for as regards the range and types of vehicles. There has been keen competition between steam and petrol as motive power, but ' circumstances ' tended to encourage the development of the latter. It has been claimed that they are more flexible and less costly to operate than petrol vehicles. At the same time, petrol vehicles are cleaner, lighter and available at any time ; whereas steam vehicles require time for raising steam, and for periodic cleaning out of boilers. They are consuming fuel all the time they are in use, even whilst standing. Five pounds of coal per mile for vehicles carrying 5-12 tons is good running ; and automatic feeds of coal and water are an attractive development. A 10-ton lorry, carrying 10-ton load, may require a 110 h.p. petrol motor or 102 h.p. heavy oil engine, for a speed of over 35 m.p.h.

Weights up to 15 tons can be transported ; and in those wagons, specialized for carrying hot bitumen and tar (q.v.) (kept fluid through insulation and by means of steam pipes), up to 3,500 gals. of liquid can be carried. Powerful 6-wheelers are employed, of over 100 h.p., with air pumps for rapid emptying. For solid material, tipping gear is employed that is either mechanical or hydraulic, tilting either backwards, or both sides (Fig. VII.7).

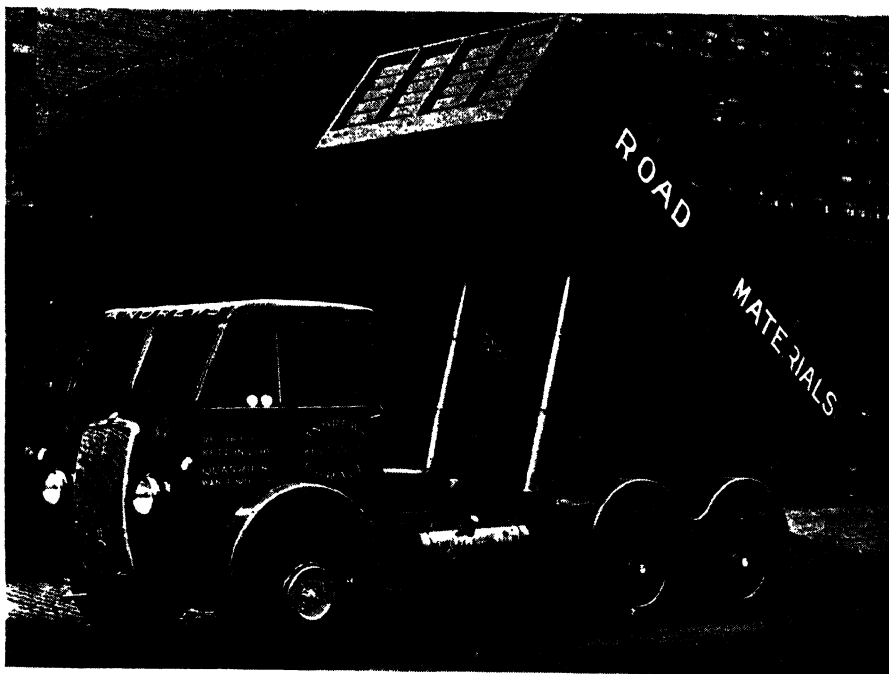
Most important it is for the road constructor that manufacturers of heavy wagons are realizing more and more the value of pneumatic tyres. They are making his job much easier by the reduction of the wear and tear of their vehicles, and through the temptation of the lower cost of licences and higher permitted speeds.

Loaders.

It is remarkable how seldom mechanical loading of broken stone, excavated material, etc., is adopted in connection with road works.

Screens.

Power-driven screens are seldom used on the road, even though they are very suitable for screening such material as old macadam, where the quantity is sufficient to justify their use.



By the courtesy of Messrs. Fodens Ltd.

FIG. VII.7.—Tipping Lorry.

Not only do they effect a reduction in cost but they produce material that is cleaner and better graded than can be obtained by hand screening. Moreover, by separating the material into various grades on the road, they enable these to be sent direct to their respective destinations and often save double handling and transport.

Miscellaneous Accessories, Tools, etc.

Brushes, squeegees, buckets, pouring cans, sett rammers (26–52 lb.) and asphalt rammers (10–32 lb.), shovels, and the host of tools and light plant amongst the roadmaking appliances, cannot be referred to

in detail. Suffice it to say that here also the industry is well catered for ; and that improvements are continuously being developed. Road danger lamps exemplify this, by giving clear warning in all directions by means of two types of lenses ¹⁰³ ; they use only $\frac{1}{4}$ pt. of paraffin in 2 days. Water carts, and even living and sleeping vans, offer a range of choice.

Special brooms are manufactured to withstand the action of tar, and for use in the tropics, and to behave like squeegees. They are made of selected proportions of Bahia bass, cocoa fibre, and steel wire.

Little critical information is available about the smaller tools used in roadmaking, so that the discussion by J. E. Everett on shovels and brushes is welcome ⁶⁰¹.

PART VIII

CLEANSING, GRITTING, ETC.

The general adoption of road surfacing materials of an impervious character and of surface dressing with tar or bitumen revolutionized street *cleansing*. Not so many years ago the majority of roads were of macadam or gravel and were thickly covered with mud in winter and dust in summer.

Outside towns little was done to deal with these conditions, and in towns it was possible only to scrape or sweep off and cart away the mud or to sprinkle with water to keep down the dust. Winter conditions were particularly destructive whether the mud was left on the road or removed, and long spells of dry weather resulted in serious damage, unless adequate watering was possible.

Street watering is now practised to a very small extent and is usually limited to spraying a width of 2 or 3 ft. near the kerb, in hot, dry weather. The reduction of horse-drawn traffic to a very small proportion has further reduced the necessity for watering and cleansing.

The removal of large quantities of mud was in fact the removal of the road surfacing material itself, and caused considerable damage to the road. Roads of the modern impervious type can be subjected to the small amount of sweeping now necessary without damage.

Gritting increased with the general adoption of impervious surfacing, many types of which gave rise to serious complaints of slipperiness and dangerous skidding. At one time grit was applied only to such materials as wood blocks and stone setts, and generally only during frosty weather. With some types of bituminous roads gritting has been found to be necessary whenever the surface is wet.

These conditions have been overcome and the amount of gritting required has already declined substantially. Where this treatment is necessary the material should not exceed $\frac{3}{8}$ -in. gauge—smaller is preferable—and care should be taken to select material which will not damage rubber tyres to any appreciable extent. For instance, crushed flint is excellent if it does not exceed $\frac{1}{4}$ -in. gauge but is very destructive when $\frac{3}{8}$ in. or larger. It has been found that for mastic asphalt $\frac{1}{4}$ -in. crushed flint freely enters the asphalt and provides for some considerable time a coarse 'sand-paper' surface which is almost ideal. Pea

gravel ($\frac{3}{8}$ in.) is satisfactory for wood paving, but is seldom required when suitable and adequate bituminous surface dressing is provided periodically. A soft stone liable to crush and form a slime or paste, such as some limestones, should be avoided. In the days of water-bound macadam, some stones formed a very slippery film following frost.

PART IX

PUBLIC RELATIONS

I

STREET WORKS

Mains and Cables in Highways.

For many years, and particularly since the advent of motor transport, the subject of road opening by public utility undertakers and of alterations to highways affecting the works of such undertakers has given rise to acute controversy.

The latter is particularly involved and difficult. The present state of the law relating to these matters is admittedly unsatisfactory, being largely controlled by enactments made 100 years ago, e.g. Water Works Clauses and Gas Works Clauses Acts, 1847.

Not only is the law unsatisfactory but it varies in relation to different undertakers and in different local government areas. For instance, in London the water undertakers are responsible for making good the pavement of any street which is injured by reason of the breaking, bursting or want of repair of their pipes³³⁰. A result of such an occurrence is seen in Fig. IX.1. In the provinces the water undertakers are not liable apparently for any such damage, except where negligence can be proved. On the other hand, both gas and electricity undertakers in London and the provinces are liable to proceedings for nuisance when damage is caused by leakage, explosion, etc.³³¹. In London also, the highway authority is entitled to execute works in connection with road openings made by public utility at the expense of the undertakers.

The aspect of the question of greatest interest to highway authorities is that relating to the extent to which they are liable for the cost of alterations to public utility works arising in connection with highway improvements.

Several serious efforts have been made to secure agreement upon an amendment of the law, clarifying the position and defining the responsibility of either party upon a reasonably satisfactory basis.

A joint negotiating committee comprised of representatives of

utility undertakers and highway authorities was set up in 1925 and successive drafts of a clause were produced in 1926, 1928, and 1934. The Clause finally agreed by the negotiating committee may be summarized briefly as follows :

- (1) Definitions of the meaning of 'highway,' 'apparatus,' 'plan and section,' 'prescribed highway,' and 'unbuilt-on land,' as used in the Clause.



By the courtesy of Messrs. Highways Construction, Ltd.

FIG. IX.1.—Result of a Burst Water Main under an Asphalt Surfaced Roadway.

- (2) Undertakers to give notice of proposed works, accompanied by plans and sections, prior to the commencement of the works. The highway authority to approve or disapprove as soon as reasonably possible, but if they disapprove they must signify this within 28 days.
- (3) Where it is proposed to lay apparatus in a highway in respect of which the Council may have any alteration or improvement in contemplation, they may require the undertakers to lay the apparatus in any abutting land in respect of which an improvement line or standard width has been prescribed under any enactment or town planning scheme. If the cost of laying the apparatus exceeds the cost of laying it in the highway the undertakers shall be entitled to claim repayment

of the excess from the Council, but if the cost is less the amount owed is payable by the undertakers to the Council.

- (4) The work to be executed by the undertakers under the reasonable direction of the surveyor to the Council, and to his reasonable approval.
- (5) The highway to be restored by the undertakers to the condition in which it was immediately before being broken up, and the undertakers to make good to the like approval any subsidence of the highway arising within six months of the completion of restoration. The Council may however give notice to the undertakers that they themselves desire to undertake the reinstatement of the highway, in which event the undertakers shall be responsible only, for the restoration to within six inches of the surface of the highway. The reasonable cost of restoration of the highway by the Council is recoverable from the undertakers including the cost of making good any subsidence of the highway occurring within 6 months.

The undertakers may be required to pay to the Council the actual cost incurred in respect of the reasonable supervision of the work of the undertakers by the Council.

If the Council give notice that they will undertake the restoration of the highway, they are required to indemnify the undertakers against any claims, damages, and expenses in respect of any accident happening after the expiration of 72 hours (excluding Sundays), from the receipt of notice from the undertakers that work has been completed.

- (6) A Council is required to give 28 days' notice before making any alteration to, or reconstructing a highway, to all undertakers having apparatus in such highway, and within that period, undertakers may give notice that, in consequence of the proposed works it will be necessary to remove, alter, or divert their apparatus, and the reasonable cost of such work may be recovered by the undertakers from the Council, provided that if the undertakers lay their apparatus with greater cover than before, or if they provide apparatus of greater dimensions the cost to the Council shall not thereby be increased. In deciding the amount which the Council shall pay regard shall also be had to any increase in the effective life of the apparatus.
- (7) The undertakers shall not open up at any one time an unreasonable length or width of a highway or unreasonably impede traffic.

- (8) Damage to a highway by explosion or like occurrence of a gas main *arising out of an act or default* [Authors' italics] on the part of undertakers shall be made good at the expense of the undertakers.
- (9) Where any apparatus has been laid in a grass verge or roadside waste the Council shall not be liable for damage caused by any roller, plant, or road material required for work in the highway.
- (10) Disputes to be referred to an Arbitrator nominated by the President of the Institution of Civil Engineers.

The negotiations finally broke down upon the question of the incidence of the cost of removing mains and cables consequent upon a highway alteration, the highway authorities refusing to accept the provisions included in the draft clause.

Following this deadlock, Parliament, early in 1938, appointed a Joint Committee of the House of Lords and House of Commons to report upon 'The Breaking up of Streets by Statutory Undertakers.' The reference to the Committee included the consideration of the Gas Works Clauses Act 1847, the Waterworks Clauses Act 1847, the Electricity Supply Acts 1882-1936, and the Electric Lighting (Clauses) Act 1899, so far as they relate to the breaking up of streets for the purpose of laying pipes, and other works, and to report what, if any, modifications of these provisions should be made to meet modern conditions, with a view to their incorporation in future Bills and Orders promoted by statutory undertakers.

Evidence was given before the Joint Committee on behalf of Public Utility Associations ; the County Council Association ; the Association of Municipal Corporations ; the Urban District Councils Association, and, (by one of the Authors), on behalf of the London County Council, the City of London, and Metropolitan Borough Councils, and the Railway Companies. The case submitted by these bodies was agreed at length by Counsel.

The clause finally submitted by the negotiating committee formed the basis of discussion before the Joint Committee. It soon became clear that the principal matter in dispute was whether the cost of removal or alteration of apparatus, rendered necessary in connection with the widening or alteration of a highway should be borne by the highway authority or by the undertakers.

In their report the Joint Committee, after reviewing the evidence and arguments of the respective parties, stated that, in their view, "the broad principle which should determine the incidence of liability for such costs, is that they should be borne by the party which initiated the proposal to effect the alteration of the highway which necessitated

the removal or alteration of the apparatus, and so entailed the cost. This will, almost invariably, be the highway authority. . . . This general proposition that the cost should be borne by the highway authorities should be subject to important qualifications." The qualifications recommended by the Joint Committee were :

- (a) Any dispute as to whether any alteration of apparatus is rendered necessary by a highway improvement, should be settled by arbitration. (All parties were in agreement with this.)
- (b) If, when a highway authority receives notice from undertakers of their intention to lay new apparatus in a highway, the authority advises the undertakers of their intention, at an early date, to execute works of alteration to the highway, and such works are, in fact, carried out within a period of say, 2 years, the cost of any removal or alteration of the newly laid apparatus, consequent upon the alteration of the highway, should be borne by the undertakers.
- (c) If, when a road alteration is being carried out, undertakers take the opportunity to substitute improved apparatus, or to lay apparatus at a greater depth, "any additional cost attributable to the *greater dimensions* [Authors' italics] of the substituted apparatus, or the depth at which the apparatus is laid should be borne by the undertakers."

This paragraph is not very clearly worded. The intention of the Committee, no doubt, was that extra cost involved by *any* improvement in the apparatus should be borne by the undertakers, although they mention, only "greater dimensions" as an improvement.

It is understood, also, that a highway authority would not be liable for any part of the cost of any apparatus unless it arose in consequence of an alteration to a highway.

- (d) If when apparatus has to be moved new apparatus is provided in its place, and the undertakers benefit from the extended life of the apparatus, the undertakers should bear a part of the cost proportionate to the amount they will be saved in future replacements by reason of their being deferred. Where alteration of apparatus is consequential upon the mere restoration of a road to its original level, following subsidence, the undertakers should bear the cost of alteration to their apparatus.

In some respects the existing position of the City of London and the Metropolitan Boroughs is far more favourable than that of provincial highway authorities, in relation to the laying of mains and

cables in highways within the Metropolitan area. They strenuously opposed any alteration in the law which would curtail their powers. It was submitted that, although some of the provisions proposed by the negotiating committee's clause would be of some value, they would not counterbalance the losses in other directions, and the authorities much preferred that the law should remain as it is. The Joint Committee, however, were of opinion that, whilst the present rights of the London authorities should continue, the rules for determining the incidence of liability for altering or removing apparatus should conform to those which they propose should operate outside London. They recommend, also, that the period of 12 months from the date of original reinstatement of the road, during which the undertakers are liable to make good any subsidence should be reduced, in London, as elsewhere, to 6 months, as proposed in the Clause of the negotiation committee. It had been urged by the Metropolitan authorities that the period should be increased to 3 years; and they produced evidence of cases where they had been required to bear heavy cost in making good subsidence after the expiration of 12 months (Figs. IX.2 and IX.3).

The Joint Committee state, in their Report, that they have not attempted to draft a clause to form a basis of legislation, but have stated the conclusions at which they have arrived, in general terms. Apparently they accepted those parts of the Clause of the negotiating committee, in regard to which there was no serious disagreement by the parties concerned, and made definite recommendations in respect of the matters in dispute, only, as indicated above.

Highway authorities, and particularly those in London, were disappointed by the decisions of the Joint Committee, as it was felt that, in some respects, they unduly favoured the undertakers. For instance, it appears to be scarcely fair that, where an authority has acquired land, generally at considerable expense, for a road widening, and thereby provided facilities for undertakers to lay additional mains, often at greatly reduced cost, the authority should be required to bear the full cost of relaying existing mains.

It is difficult to see any justification for allowing the undertakers, after opening up a road, to shift upon the highway authority all liability for consequential damage to the road, occurring after a period of 6 months. It might be thought that the principle, advocated by the Joint Committee for determining the incidence of liability in regard to alterations to mains, viz. that the cost should be borne by the party which initiated the proposal, might reasonably be applied in this case.

The Joint Committee recommended that their decision in reference to the incidence of liability for the cost of relaying mains in highways

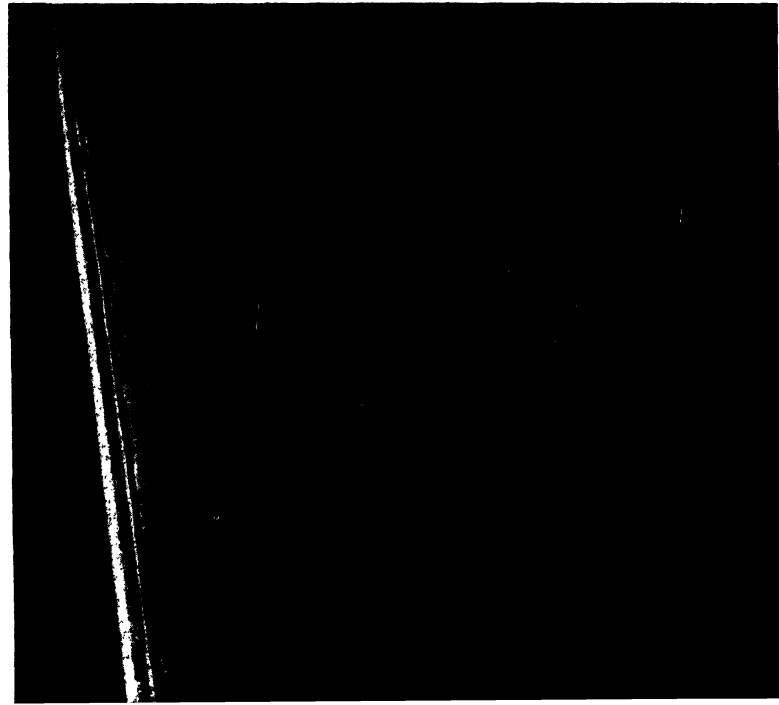


FIG. IX.2.—Settlement of Roadway, due to Sides of a Trench giving way.



FIG. IX.3.—Settlement of a Roadway, due to the sides of a Trench giving way under a Concrete Slab extending 6 in. beyond the Trench on either side. The concrete was laid before the asphalt surfacing was reinstated.

in both cases the settlement occurred after the expiration of the 12 months' period during which the undertakers were under statutory obligation to maintain.

should apply also to bridges. There appears, however, to be no obligation upon a bridge authority to make any special provision in the bridge structure, when widening or improving a bridge, for the convenient and satisfactory construction of any new mains or cables, so that, generally, in such cases, the authority is in a position to discuss terms with the undertakers.

It is obvious that when Parliament deals with the Report some of its items will require adjustment.

It is clear also that if, and when, the recommendations of the Joint Committee become law, highway authorities will find it essential to be more stringent in regard to their requirements in connection with the refilling of trenches by undertakers, and to supervise more closely the work, than has been the general practice hitherto. Having regard to the reduced period of liability of the undertakers, it usually would not be unreasonable to require consolidation by power-rammers, and, as necessary, the use of water during the process of consolidation. In many cases, the provision of an adequate bed of concrete, spanning the trench, might reasonably be demanded, and in others the substitution of material more suitable for refilling, than that excavated from the trench.

Street Tramways.

Fortunately, these are being gradually abandoned or converted to trolley-bus systems.

The main, and probably now the only real advantage, which trams can claim, apart, probably, from low power costs, is their unit capacity which enables them to move large numbers of people quickly over long distances, but even this has been attacked by the modern omnibus, the capacity of which can now compete with that of the largest tram-cars.

The disadvantages of this system of transport are well known, but from the point of view of the highway engineer, the most important are obstruction to traffic, both by the vehicles and when the track is under repair—often at short intervals—and, where the service is frequent, the concentration of other traffic largely upon the portion of carriageway between the track and the kerb. The statutory minimum distance from outer rail to kerb is 9 ft. 6 in., and allowing for an overhang of tram-car of 15 in. this means that in many important thoroughfares the bulk of the other traffic is carried on two strips of road 8 ft. 3 in. in width.

From actual count on several occasions, it was ascertained that on one of the main London roads, approximately 80 per cent. of ordinary vehicular traffic was confined to these margins. The effect was that

some 20,000 tons out of a daily load of 25,000 tons was carried by four narrow strips of road material—certainly not more, in each case, than about 15 in. in width.

Difficulties also arise in connection with the maintenance of tram track and margins, particularly when the former does not belong to the highway authority, and especially since many tramway undertakings have been working at a loss.

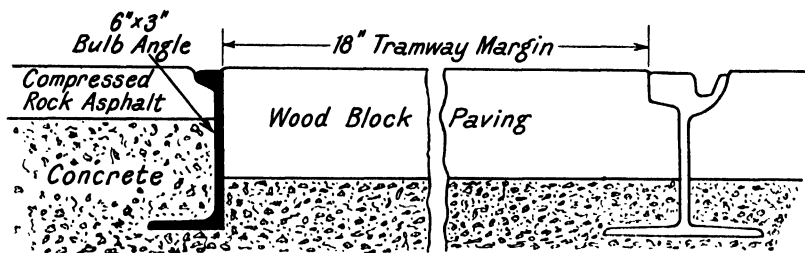


FIG. IX.4.—Bulb Angle isolating Road Breast from Tramway Track.

An immense amount of damage to the adjoining roadway can be caused by defective tramway paving and loose rails. Cars passing over the latter are liable to discharge water which has found its way underneath with great force under the adjoining paving, causing disintegration of large areas of roadway.

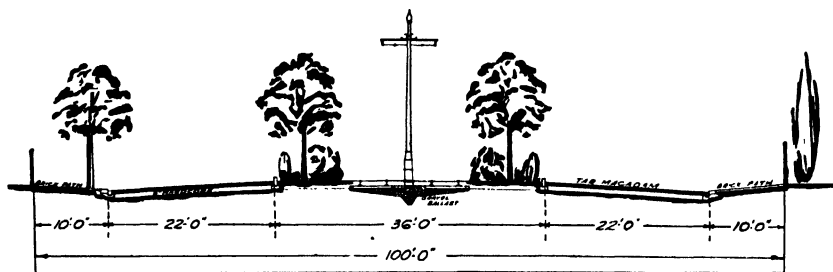


FIG. IX.5.—Central Tram Track.

A method of preventing this was adopted at Wandsworth some years ago with marked success. This consists of fixing a bulb angle immediately adjoining the 18-in. tramway margin, as illustrated in Fig. IX.4.

It is true that the liability of maintaining the whole area of tram track is borne by the tramway undertaking, but many highway engineers are of opinion that their authority would be better off, from a financial point of view, if the tram track was removed and they had to bear the cost of the whole road.

This may be true under circumstances similar to those described above, but it is doubtful whether it would be so when a tram track is satisfactorily maintained, and there is ample width of carriageway on either side to permit reasonably free lateral movement of traffic, or where the tram service is such as to interfere to a small extent only with the use of the track by general traffic.

The foregoing disadvantages are not experienced where a tram track is laid independently of the highway proper.

Probably the earliest example of this type of tramway is that constructed by one of the Authors at Southend-on-Sea in 1912, followed immediately by similar tracks in Liverpool and later in Birmingham, and elsewhere. For a typical section of track at Southend see Fig. IX.5.

This form of construction practically eliminates obstruction, both from and to the tram-cars, and noise and vibration—the rails being laid on sleepers. Moreover, a higher speed is permitted, the riding is easier, the conditions more pleasant, and the cost of construction, maintenance and operation, less.

Private Street Works.

After the 1914–18 War there was a growing criticism of local authorities for alleged extravagant specifications for the construction of private streets. This arose largely from numbers of people being forced to purchase a house to obtain a home, owing to the impossibility of renting one.

To do this, many had to borrow to the limit of their resources and when, subsequently, they received a demand for private street works charges, they found themselves in a difficult position. This led to an agitation in favour of the whole burden being transferred to the shoulders of the ratepayers.

It was contended that upon the site of a road being thrown open as a highway with free access by the public, the cost of construction should be borne by the rates.

The main objection to this view is that primarily the roads are made for profit, and that those who take the profit should bear the cost of construction to such a standard that when the highway authority assumes responsibility for the future maintenance of the road, an undue burden will not be cast upon the ratepayers.

It is pointed out that in many cases land which is of agricultural value, becomes building land, worth many times that value, merely by the provision of roads and sewers, and that these charges are properly classed as part of the cost of development. The real difficulty of the position is that in the majority of cases the person who takes the profit does not pay the cost.

Many people even now purchase property without realizing that the cost of road works is a charge upon the abutting premises, and others, although aware of the fact, have no alternative but to accept the builder's terms and hope for the best.

In many cases estate owners have, by arrangement with the local authority, made up private streets at their own expense, and have subsequently apportioned the cost upon the properties as sold. This arrangement appears to have given satisfaction to purchasers, and to have facilitated disposal of the property.

There may be cases where the local authority might, without serious detriment to the ratepayers, adopt a less costly specification for private streets, but the majority of councils have already appreciated the position and cut their requirements to a minimum. The Ministry of Health has assisted in this direction by agreeing with the Institution of Municipal and County Engineers a specification ³⁵⁶ for private street works which local authorities are urged to accept as indicating a reasonable standard under normal conditions.

Wide variations in the character of materials available in different parts of the country, and in other local conditions rendered impracticable the preparation of a specification which could be imposed upon all local authorities, but in most cases there should be little difficulty in drafting requirements broadly equivalent.

The position of local authorities in this matter would be rendered much easier if they were in the position to prevent roads laid out for residential purposes from being used for heavy traffic. At present they have practically no such power, and they know that unless all roads are constructed to carry some amount of heavy traffic, they may quickly become a serious liability.

Given this power, however, they could safely, in many cases, adopt a lighter and less expensive form of construction.

The two most usual forms of attack upon the present specifications are first that footpaths should not be paved with either natural or artificial stone, but that tar paving is quite good enough, and that this need only be about 4 ft. wide, the remainder of the path being gravel.

Local authorities reply that tar paving may be fairly satisfactory where there is no risk of any considerable openings being made subsequently, but that where this takes place, the path will probably be ruined, whereas slab paving can easily be removed and reinstated; moreover, it does not require periodical surface dressing as does tar paving. Where the paths are of sufficient width, it is often practicable to pave part only. The second objection usually relates to the formation of the carriageway. In many cases, concrete is specified, and there appears to be objection to this material on the ground that

as it is often used for main roads, it is obviously an unnecessarily expensive form of construction for the ordinary private street. The fact is that a 6-in. or 7-in. concrete road is often cheaper than any other reasonably satisfactory form of construction, such as hardcore and tarmacadam. This is generally the case where there is no existing foundation and the carriageway has to be completely formed.

Often there is substantial saving in cost of excavation and removal of surplus material, owing to the fact that a foundation of hardcore or other cheap material must be thicker than concrete, and excavation to a greater depth is therefore necessary.

A serious difficulty often arises in regard to the basis of apportionment. If the local authority proceed under Sec. 150 of the Public Health Act, 1875, there is no alternative but to charge upon the basis of frontage to the road. This often causes great hardship, as a frontage may be charged far in excess of the relative advantage it derives from the road. This is particularly the case where a road is constructed adjoining the boundary of the land of another owner, and causing depreciation in the value of his property. On the other hand, a local authority is entitled under the Private Street Works Act, 1892, to apportion the cost according to degree of benefit. This, however, is often most difficult to assess and consequently many councils hesitate to depart from the basis of frontage only.

It is rather difficult to understand this attitude, as in most cases it is a more equitable method, and if the original apportionment should be amended by the court, it does not seem to matter very much to the council so long as they recover the whole of the cost.

The difficulties of apportionment are often accentuated by the lay-out of the roads.

For instance, in many cases building plots are long and narrow, so that corner plots with a relatively small main frontage have deep flanks abutting upon the side road. As a consequence, the owners of the latter often have to pay five, six, or more times the charges paid by other owners.

It frequently happens also that there are few direct frontages upon the flank road, so that apportionment upon 'degree of benefit,' whilst adding substantially to the charges upon the direct frontages, may leave the flank property with a substantial burden.

This aspect of the question gives rise to more hardship and dissatisfaction than any other, and apparently seldom, if ever, is given the slightest consideration when the lay-out of a building estate is being designed.

There is one other matter which may cause hardship, under the procedure laid down by the 1892 Act. Any frontager may appeal

against his apportionment, and the Court, after hearing the appeal, may make important alterations in the basis of the apportionment affecting other frontagers who have been unaware of the proceedings. It appears to be highly desirable that every frontager should be given an opportunity to be heard at the appeal proceedings.

At the request of the Government Departments concerned, the Institution, in 1944, prepared from model specifications ³²⁹, in connection with the advance preparation of housing sites, viz. No. 1 : Concrete Roads using Mechanical Methods of compacting concrete ; No. 2 : Concrete Roads using Manual Methods of compacting concrete ; No. 3 : The use of Pitched or Hardcore Foundations with Single-course Tarmacadam surfacing ; and No. 4 : The use of Pitched or Hardcore Foundations with Asphalt or Single Course Bitumen Surfacing. These Specifications may be taken as supplemental to that already mentioned ³⁵⁶.

The Specifications include some General Clauses and deal with Materials, Workmanship, and Drainage. No. 1 includes Appendices dealing with (1) *Sieve Analysis of soil for use in sub-base* and (2) *Determination of Specific Gravity moisture Content* ; No. 2 repeats Appendix (1) of Specification No. 1, and has an Appendix (4) relating to *Allowance for the Bulking of Aggregate*. No. 4 includes specification clauses for three alternative surfacing materials : A, *Rolled Asphalt Surfacing* ; B, *Single-course Bitumen Macadam—Granite, Limestone, or Slag Aggregate* ; C, *Single-course Bitumen Macadam—Gravel Aggregate*, also a clause dealing with *Transportation and Laying*.

II

TRAFFIC CONTROL

Traffic has never been examined in this country in an organized manner, and until recently no attempt has been made to study it scientifically. Fragmentary and unsystematic attention has been given to local problems ; and action has been taken mainly on earnest and anxious judgment—not knowledge. Traffic volume and speed and transverse distribution, road capacity and congestion, and behaviour of vehicles at intersection and while overtaking, have been investigated almost entirely in America (for instance ⁵⁸⁵) and Germany, and only from 1935 onwards. (For aids in taking traffic statistics, see ³⁹⁶.)

For 10 years or more, Lt.-Col. O'Gorman has been urging the organization of the scientific analysis of traffic flow ⁵⁸⁶ ; and at last the Ministry of Transport appointed, in 1946, a Committee.

The study of the reciprocal relations between traffic and the road—

between road design and road usage, methods of control in various situations and conditions, and the safety and smooth running of all units of the road, has required, in America, the advent of a new type of highway technician—the traffic engineer. His practical expert knowledge would also assess the conditions of an accident, for the benefit of the culprit, the sufferer, the highway authority, and the police, through an independent professional opinion.

Its control is a police matter ²⁴⁸; but under pressure of growing congestion and loss of life, it has received increasing attention from the Government. The earliest of its obvious administrative acts was the establishment of the first roundabout in Parliament Square (Regulation, Feb. 6, 1926). Later one-way streets were scheduled, the first in London being Long Acre, August 1, 1924; and it is on these lines of traffic flow ²⁷⁹ and automatic signal control (q.v.) that the subject is mainly being developed.

The connection of traffic with the road within the limits of this book is twofold: the *weight* of traffic that the road builder has to meet, and the *area* occupied by the vehicles for which the engineer has to plan the road; and the central authority has to control both the area and the speed.

The quantity of traffic is usually measured by the tonnage passing per unit of time—the hour or the day; and the engineer's prime problem is to design a road that will carry the estimated traffic at some future period based on the quantity at the present time.

The usual way of classifying quantity of traffic is the use of the terms 'light,' 'medium,' and 'heavy'; which are at best extremely vague.

Signs and Signals.

The *Report of the Departmental Committee on Traffic Signs* (1933) of the Ministry of Transport discussed this question in detail and embodied a number of recommendations.

In 1943 the Minister of Transport appointed a Departmental Committee "to consider the system of road traffic signs, and other cognate means of controlling traffic on roads, and to make recommendations."

The Report of the Committee ⁶⁰⁶ was presented in November 1944, and dealt with every phase of the subject. The extent and complexity of the problem of present-day traffic control is indicated by the fact that the Report comprises over 100 pages, 40 of which are of drawings of signs.

The Report is divided into five sections, respectively headed General Considerations; Roadside Traffic Signs; White Lines and

other Traffic Signs on the Carriageway ; Light Signals ; and Markings of Crossings.

Many new and amended signs are recommended and these are divided into three broad classes, viz. :

- (i) Where the change-over should be as soon as practicable ;
- (ii) Where the change-over should be made within say 3-5 years ; and
- (iii) Where the change-over may be introduced when renewal of signs becomes necessary.

The size, lettering, and height of signs is standardized, it is recommended, however, that the supply of traffic signs, both permanent and temporary, by Approved Organizations should continue to be permitted. There will be general approval of the recommendation that there should be uniformity of practice in the display of street name-plates and street numbers.

It is recommended that traffic markings on carriageways should be white, but that self-cleansing reflector studs of approved pattern, set in longitudinal white lines should, formally, be authorized, having regard to their proved benefit to traffic. It is pointed out, however, that reflector studs are of little value where the standard of street lighting is such as to render the use of headlamps unnecessary, and it is recommended that this type of marking should not be used on pedestrian crossings. The opinion is expressed that, generally, the distance apart and gaps in intermittent markings might be increased without disadvantage.

No major alterations are suggested in existing traffic light systems, but that, as an experiment, a selected group of signals might be operated with the 'Red with Amber' signal omitted to determine whether increased safety, without increased delay to traffic, can thereby be obtained.

It is stated that, throughout their deliberations, the Committee had in mind the desirability of conforming, so far as practicable, to agreed International practice, but, with some reluctance, they recommend certain modifications, particularly in signs indicating bends, and they express the opinion that symbols, without explanatory lettering, are not generally satisfactory, particularly where they are of a prohibitory or mandatory character, and that the majority of the signs adopted by the International Geneva Conference of 1931 are not suitable for use in this country.

Reference is made in both reports to London Traffic (Lighting and Guarding of Street Works) Regulations, 1927, made by the Ministry of Transport under the London Traffic Acts of 1924 and 1930. The opinion expressed in the 1933 Report is that those regulations which "have worked well in London might be more widely followed." It is

doubtful whether this view will be endorsed generally by those who are responsible for the execution of works to which they apply. Careful observation has proved that in only a few cases is there strict compliance with the regulations.

It has been alleged that the placing of red lamps not more than 12 ft. apart throughout the length of long excavations is extravagant and unnecessary, and in the 1943 Report, it is recommended that 20 ft. should be substituted. The most general objection, however, is to the obligation to provide "*adequate and effective* protection" around any excavation "of such a nature or in such a position that foot passengers or vehicles are in danger of falling into it." Apparently this places the whole responsibility upon those making the excavation to prevent accidents in any circumstances. For instance, it may be held to mean that the protective works must be such that a vehicle weighing 20 tons or more must be prevented from falling into the excavation however carelessly it may be driven. Apart from the question of cost, any such protection must be of such a character as seriously to interfere with the execution of the works in many cases, and in some to render their execution impracticable.

The latter Report stresses the importance of practice in the display of street name-plates and numbers, and recommendations are made in reference to the position and character of the plates and numbers.

Much in the 1933 Report was consolidated in the Traffic Signs (size, colour and type) Provisional Reflectors 1933, and "Directions issued by the Minister of Transport in pursuance of Section 48 (1) of the Road Traffic Act."

There are several important firms that specialize in traffic signs ; and there are available a large variety of prescribed and original types of warning signs and symbol plates ; and of prohibitory, mandatory, approach, and direction signs. These are of metal (often of aluminium), in silhouette or embossed, and coloured as may be required.

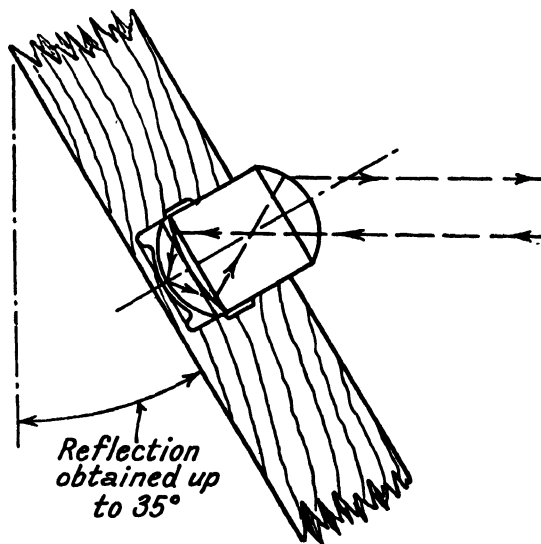
The following signals all depend for their action on external illumination, whether it be daylight or the usual street or special lighting, or by the headlights of motor vehicles. They all serve the same purpose of giving directions or warnings to traffic, whether by means of words or signs, or, in some cases, road posts.

A. The simplest type consists of transparent signs, made visible by light reflected through them from behind, by mirrors or prisms, or by an associated illuminating unit from the front.

B. Directions and signs may be made of separate metal or enamelled letters or complete words, on which small reflecting units are arranged, so as to show up their general shape ; and are so constructed as to throw back light falling upon them at as wide an angle

as possible, which is in the neighbourhood of 90° . There are two main principles on which these units work :

- (i) A thick cylindrical lens, curved in front and flat or slightly curved behind, and furnished with a reflector at the back (Fig. IX.6). It is interesting to note that silver reflects 90 per cent. of the light falling on it, and chromium only 67 per cent. ; the latter has, however, the great advantage that it does not tarnish in the air. (See also ¹⁰⁰.)



By the courtesy of The Franco-British Electrical Co., Ltd.

FIG. IX.6.—Lens Type : showing the Path of the Light and the Limiting Angle of Effective Use.
Reflecting Unit.

- (ii) A flat, disc, smooth in front but cast behind into right-angled tetrahedral prisms, whereby incident light is totally refracted back toward the source of the illumination (Fig. IX.7).

C. Lettering is made up of sheets of glass of appropriate shape and set in frames, and provided with a means of reflection behind so that the glass shows as a uniformly illuminated area.

Danger Light Signals, etc.

Road Beacons. Avoidance of accidents, particularly those associated with night driving outside towns, has led to the development of a warning light to indicate the position of cross-roads.

It is well known that anything moving catches the attention better than anything stationary, so that a periodic light, on light-house principles, has been produced for this purpose.

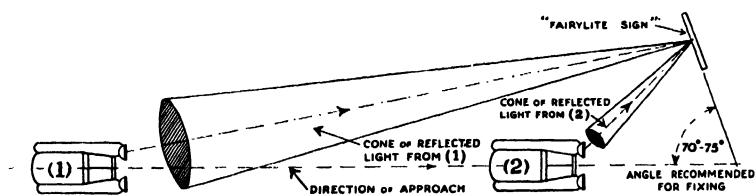
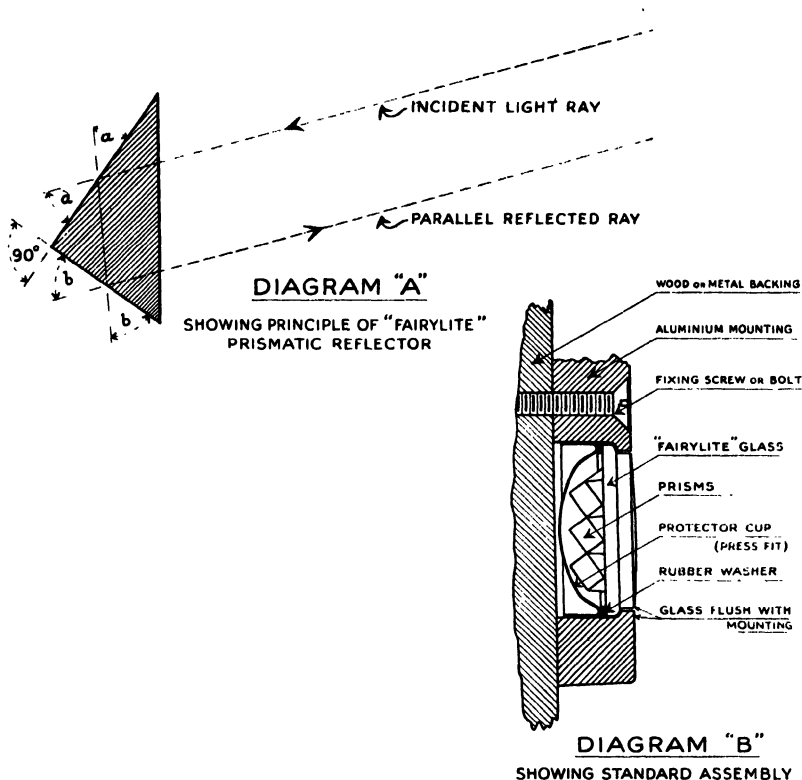


DIAGRAM "C" — SHOWING HOW THE "FAIRYLITE" SIGN OPERATES IN PRACTICE

By the courtesy of Fairylites, Ltd.

FIG. IX.7.—Prismatic Type : showing the Path of the Light and the Angle of Optimum Setting. Reflecting Unit.

A movable obstruction signal has been designed on this principle primarily for police control of traffic.

Traffic Warning Lights are of so great variety that they can only be referred to generally :

Danger Lights ; ' Road Up ' signs, etc. The familiar red lanterns usually burn paraffin, and one filling lasts 30–48 hours. The warning colour may be a simple red globe, or the light may escape through red prismatic lenses.

Traffic control signs during road repair may consist of simple notices, reinforced by reflecting lettering, or of portable electrically illuminated wording. It has been emphasized that such warnings are preferable to the red and green flags waved by a workman, the operation of which may be open to misunderstanding. This has now been put on a proper basis by means of a portable adaptation of the automatic traffic control signals, worked by electricity, or by dissolved acetylene.

A new type of automatic traffic light has been devised for temporary installation or where electricity is not available. It operates by clockwork through a system of cams which can easily be changed according to the desired phases of the lights ²²⁴.

Flood Lighting Lamps. In addition to the usual acetylene and naphtha flares, paraffin vapour burning on a mantle is used.

White Lines and Road Direction Signs.

The 1943 Departmental Committee Report refers in some detail to the laying down of white lines and reflecting studs for the control and direction of traffic, and makes some important recommendations as to their use.

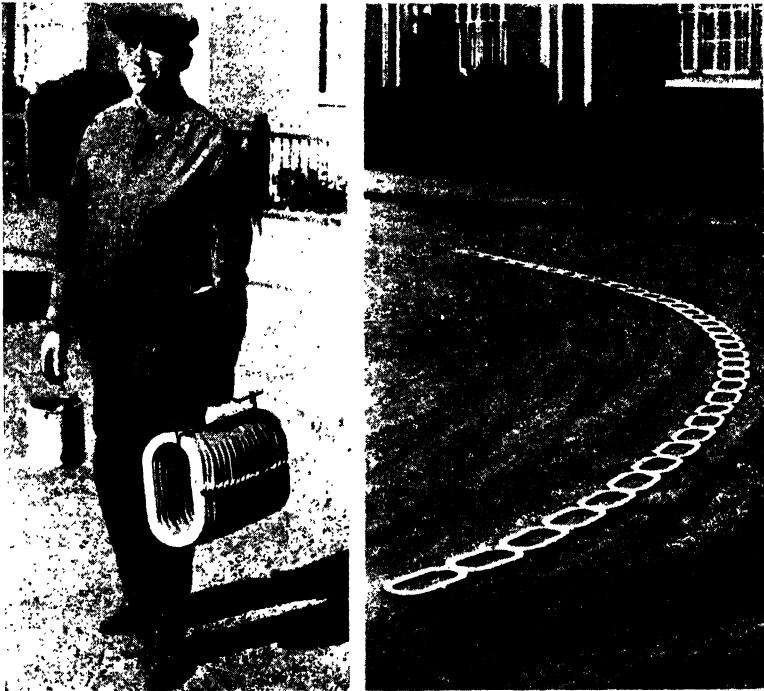
The material employed for white lines is of paint or plastic, or some form of studs or of block capping or inset ; and the ideal substance must have the following characteristics :

- (a) quick drying (if of the nature of paint) ;
- (b) adherence or permanent fixing to all surfaces ;
- (c) permanence of colour ;
- (d) resistance to the attack of atmospheric influences, water, tar, bitumen, oil, grease, acids, etc. ;
- (e) maximum length of life ;
- (f) simplicity of application ;
- (g) visibility under all circumstances ;
- (h) non-skid (if of metal) ;
- (i) low cost.

Paints. These usually have an enamel or shellac base, and some perhaps contain rubber ; but so much secrecy is preserved about

them that classification is impossible. (For detailed examination into the requirements of road paint, see ⁵⁵⁴.)

The colour first supplied was white ; but some hold the opinion that yellow or orange is to be preferred on account of alleged increased visibility in misty or foggy weather and in half-light, and under conditions of snow. Other colours can be supplied, but white or yellow are of the greatest all-round usefulness, and are those required by Authority.



By the courtesy of Messrs. Johnston Bros., Ltd.

FIG. IX.8.—10-yd. Lynx Stencil, being transported and in use.

Investigation shows 4 in. to be the minimum desirable as the width of a white line, and that spacing of gaps between 1 ft. and 3 ft may produce the effect of flicker ⁵⁵³.

In the case of white lines, the central line (in California) may be painted wavy to indicate the approach to a point of possible danger or a direction signal ⁵⁷⁰ ; it may be specially valuable at night.

The paints can be applied to the road surface by means of a brush, or a road-line machine at a greater speed. The application of the former is facilitated by the use of stencils ; an example of a folding white-line stencil is seen in Fig. IX.8.

In general, it appears that the covering power of these paints is about 50–100 sq. yd. to the gallon, and the time taken in drying should not exceed 15–20 mins.

In recent years, *plastics* have been claiming attention as a competitor to paint. They have been found to be suitable for application to bituminous surfaces, but not to wood, granite setts, or concrete. They are not so easy to apply as paint, but harden rapidly, offer good resistance, and are reasonably white in colour but not so visible as new paint. Over 2 years they are cheaper than paint, because they do not require renewal. Application should be made during warm and dry weather, and on a clean dry surface ⁵⁵².

Much useful information on the whole matter is given in *War-time Road Note*, No. 6, Ministry of War Transport, 1943, and also *B.S./A.R.P.* 38, 1943. These deal with white lines, with special consideration for wartime limitations of materials and staff.

A preference for white lines over 'cats' eyes' has been based on the former being visible in a fog whilst the latter were not ⁵⁵³. This defect has been denied by the manufacturers of the reflecting signs.

Metal. The main forms that have been employed are blocks and discs, cappings to blocks, and insets into surfacings. The materials used consist of non-corroding steel or malleable iron covered with stainless steel, or of aluminium or nickel alloy, or brass. Their advantage lies in their greater permanence as compared with painted lines.

Studs and discs are usually round or square, and are supplied 2 in., 3 in., and 4 in. in diameter or size, the most common size being 3 in. Triangular studs, marked 'P,' are used for indicating parking places. The most usual length of shank is $3\frac{1}{2}$ in. or 4 in.

Plates usually consist of a plate $\frac{1}{4}$ – $\frac{1}{2}$ in. in thickness, 3 in. or 4 in. wide (principally the latter) and 9–12 in. long, with projecting feet or other attachments for fixing in the road.

In selecting metal fittings for road lines, consideration should be given to the following characteristics: (a) visibility, (b) durability, and (c) ease, effectiveness, and permanency of fixing.

(a) *Visibility* depends, not only upon the material of which the fitting is made, but to some extent upon the surface design. The doming of studs increases visibility, but in the interests of safety this must be kept shallow. Dome-like projections on plates, and surface rings on studs, also assist visibility as well as safety.

Non-corrosive steel with bright finish has been found to retain its brightness better than any of the other metals already in use.

(b) *Durability* depends mainly upon the character of the metal, but design is also important. Non-corrosive metal is undoubtedly the most durable for this purpose. There appears to be little to choose

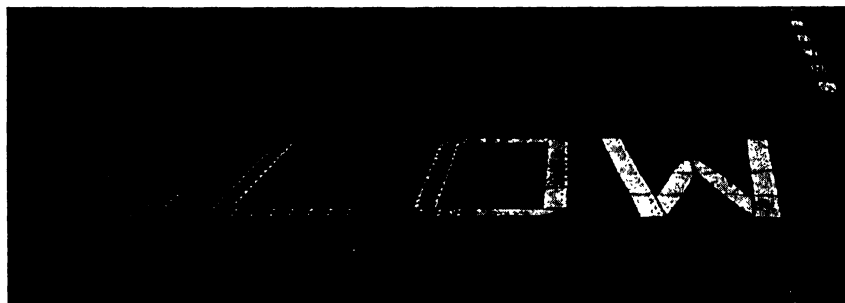
between the best castings and the best stampings, but much depends on the fixing.

Castings may sometimes be weak at the junction of the shank and disc, and of the foot with the plate ; this can be prevented only by care in manufacture.

The holes for shanks should be sufficiently deep to leave a clear space of about $\frac{1}{2}$ in. below the bottom of the shank, because, should the shank rest upon the bottom of the hole, the head will break off, sooner or later, under traffic.

(c) *Ease, effectiveness and permanency of fixing.*

Fixings of *blocks* may be designed to give a perfect key when solidly embedded, but they cannot be satisfactory in practice if it is not possible to pack them properly.



By the courtesy of The Firth-Derihon Stampings Ltd.

FIG. IX.9.—Road Sign, showing one method of forming letters.

Experience shows that a slight expansion at the root of the shank gives sufficient key in concrete, if the diameter of the hole does not exceed the largest diameter of the pin by more than $\frac{1}{8}$ in. It is usual to fill the hole with cement mortar—usually of high aluminous cement or Portland cement with a liquid accelerator and hardener—and to press in the pin until the disc is firmly embedded. The holes in the latter are essential as vents for surplus cement. For wood paving the filling may be hard bitumen run in hot. Where the road is surfaced with asphalt on concrete, the asphalt should be removed to its full depth and of at least the area to be covered by the disc, and the space filled with cement upon which the disc is embedded. It is found that when plates or discs are bedded upon asphalt or other yielding material trouble results from movement of the stud which often breaks. For macadam, tarmacadam, and similar materials with large aggregate, it is necessary to make a larger hole and fill it with fine concrete. In such cases a 'fish-tail' root to the shank is desirable.

Discs should be used for wood paving only, to which they are secured by screws.

From this it is seen that fixing is a matter of importance and of some difficulty. The fixings of many plates and discs are effective under heavy traffic, but it is obvious that the character and amount of the stresses involved have not been fully appreciated.

Reflecting Road Studs ('cats' eyes') have had considerable success both as traffic and kerb indicators. The self-cleaning type is set in rubber and this in a strong iron seating, so that traffic passing over it depresses the rubber and rubs mud, etc., off the lens ³³². It is more effective where the standard of street lighting necessitates the use of headlamps.

White Asphalt in the form of mastic has been successfully developed for this purpose.

Rubber Blocks. There are paving blocks of various materials surfaced, in various ingenious ways, with white or coloured rubber, and are inserted into the roadway in a manner depending on their form and construction. Shaped blocks are also made for the formation of lettering. The surface may be smooth, grooved, or studded.

More recently *plastic* moulded shells have been made to be filled with concrete and inserted into holes in the road about 9 in. apart.

Illuminated White Lines have been tried. These were satisfactory at night, but were less visible during the day than the more normal type. A serious defect was frequent failure due, amongst other causes, to vibration of traffic ³¹⁹. The *Methods of Providing Traffic Lines in Great Britain* has been the subject of a useful Report on the matter ³⁵⁷.

Automatic Traffic Control Light Signals.

The system of automatically controlling traffic by means of coloured lights was introduced here from America, and has developed rapidly. Fundamentally, the control consists of red and green signals, the indications of the colours being similar to that adopted in railway practice, with an intermediate amber light giving warning of change, all operated through an automatic controller.

There was, at first, a remarkable diversity of means for the production of the desired result that indicated a healthy vigour of invention and competition. Such a condition resulted in part from the wisdom of the Ministry of Transport in not making its requirements too closely detailed ⁴¹ at an early period in its development. And the current B.S. 505 : 1939 is also not too tight in its requirements. The Specification of the Ministry of Transport (1938) is considerably more detailed. By now there has been a survival of the fittest.

The value to the public of this system lies in facilitating the movement of through and cross traffic with increasing safety to vehicles

and pedestrians, and the release of police constables, allocated to point duty, to more serious occupations. The general trustworthiness of the electro-mechanical equipment now employed for this purpose has become well established. (See also ²⁷⁹.)

A *preliminary investigation* of local traffic conditions, as regards the number and types of vehicles ⁶² that pass straight ahead or to the right or left at intersections, and their average speed, will show whether an automatic system is desirable, and whether the apparatus is to be traffic-actuated with detector pads in all roads, or (in the case of lightly trafficked roads entering an intersection) with pads at the side roads only ; or whether a fixed-time cycle is preferable. After this it must be decided whether the system shall work on two or three phases, or if a simple red-overlap would control the traffic efficiently.

Examples of expressing traffic census and the control of awkward street junctions are seen in Figs. IX.10–IX.12.

It may happen that when the normal traffic is subject to violent fluctuation in amount, or to sudden incursion of horse traffic, the constable on point duty may advantageously take temporary control and especially in sudden emergency.

A decision must also be made as to the hours during which the signals are to operate. At first it was the usual practice even in London to shut off the signals between 11 p.m. or midnight to 6 or 7 a.m., but a twenty-four hours service soon became general with traffic-operated systems ; and when fixed-time cycle systems are not operated continuously, an amber globe is mounted on each post, which is illuminated when the signals are out of action. At times of emergency, the signals may be operated by hand.

The *cycle of light changes* that has been adopted is :

Red meaning STOP.

Red and amber simultaneously ; meaning PREPARE TO START but do not move.

Green meaning GO straight ahead, or to the left or right with care for the safety of others.

Amber meaning STOP IF YOU CAN WITH SAFETY.

Occasionally an additional green light, provided with an arrow, controls 'filtering' to the left against the red signal ; and a rare CROSS NOW signal to the pedestrian may be seen.

A normal four-way intersection traffic on each of the two roads may be composed of the following streams :

- (a) Vehicles (1) passing straight through either road,
(2) turning left,
(3) turning right.
- (b) Pedestrians.

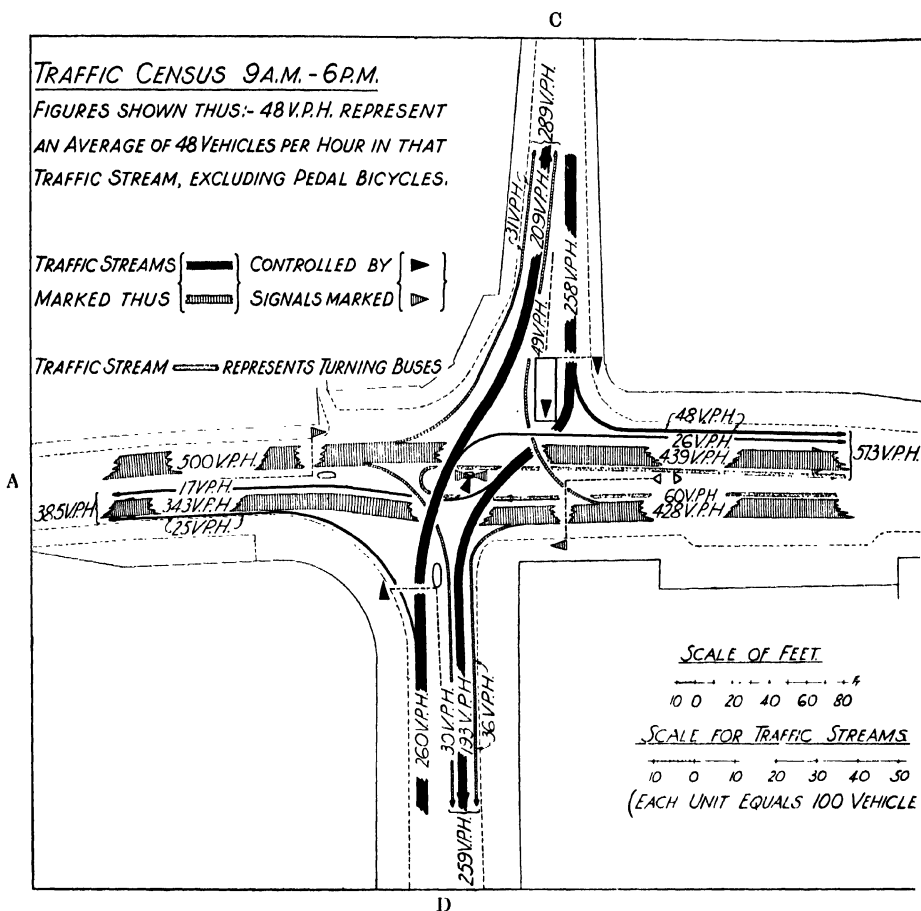


FIG. IX.11.—Traffic Census and Control.

Four-way crossing slightly staggered. The centre of the junction is the turning place for 60 omnibuses per hour.

The signals are two-phase fixed time cycle, timed as follows :

		Timing (seconds).			
		Green.	Amber.	Red.	Red and Amber.
Phase 1.	A-B	26	4½	19	4½
" 2.	C-D	19	4½	26	4½

A clear signal can only be given to either of these vehicular streams at a time when all the other streams are halted. Pedestrians should require one adequate period per cycle to proceed while all vehicular traffic was halted. This weakness is common to all systems and cannot be cured unless an 'all-red' period or a pedestrian press-button

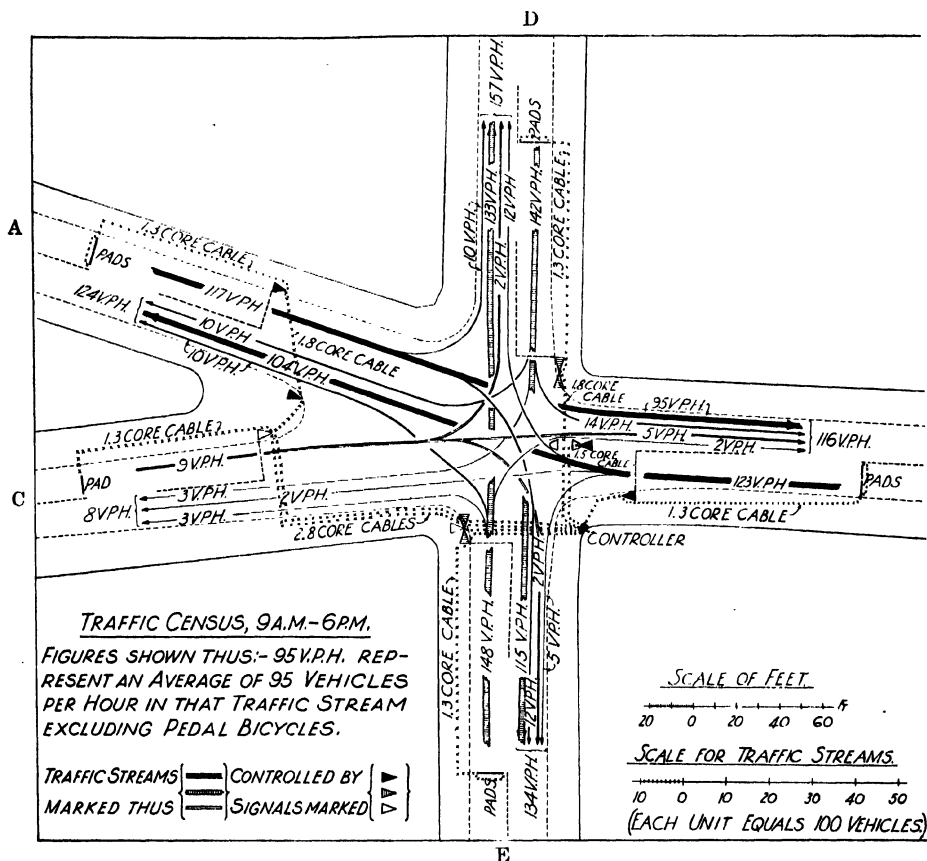


FIG. IX.12. -Traffic Census and Control.

A five-way crossing with traffic-operated signals. E-D both directions; A-B both directions; from C only - Green max. in each case 25 secs. and amber 3 to 5 secs.

control be introduced. This would necessitate the subdivision of the green signal on each road into three parts and a delay in traffic that would be difficult to justify. The adoption of this all-red period, also, would undoubtedly create more serious congestion of vehicular traffic in busy thoroughfares.

It must be clearly understood by drivers that the green signal does not imply a right to proceed *without taking ordinary precautions*.

With care and patience it is practicable on most ordinary intersections to accommodate all traffic streams on a single undivided green signal, thereby reducing very much the total length of the cycle.

When deciding the timing of the cycle it is as well to bear in mind that traffic control means control of both vehicular and pedestrian traffic. In many instances it will be found that vehicular traffic may well clear itself in a short cycle, but the time is insufficient for pedestrians to cross the road before the signals change—especially the aged and infirm. It has been found from experience that the time taken by pedestrians to cross a road is a reasonably sure guide to the minimum time which that road should be stopped, e.g. road 30 ft. wide at 2.2 ft. per sec. ($1\frac{1}{2}$ miles per hour) = 13.6 secs. plus 2 secs. brain lag = say 17 secs. The periods of the cycle may have to be increased above the defined pedestrian period according to the GO period necessary on other roads, but it should never be fixed below it. Now that pedestrians are watching the signals a possible period of only 5 secs. is bad and should be extended to allow them a safe period. In support of this it will be noticed that the Ministry of Transport specification states that the period of the red or green lights shall not be less than 12 secs. The standard amber period is now 3 seconds but the abolition of the amber light is being advocated.

The length of the total light cycle varies between the limits of 30–120 secs. and is usually 30–90 secs. or 40–120, according to the bulk of the side-street traffic ; it should be as short as possible. There is usually an optimum length of cycle for any particular position, which is about 40–80 secs. Too long cycles lead to the accumulation of traffic in the centre of the road waiting an opportunity to turn right ; and they try the patience of the motorist and pedestrians and lead to non-observance of the signals ; whilst too short cycles occasion too frequent stops and cause congestion of traffic.

When a series of signals is linked together through a master controller for co-ordinating working of a long street, the ideal aimed at is for a vehicle travelling at an average predetermined speed to meet a continual series of green lights so that it may pass through without interruption. This may be interfered with by too fast or too slow travel, or by congestion due to an excess of vehicles in a particular section.

However carefully such a fixed-time cycle may be devised, even with a fairly uniform flow of traffic along each of the intersecting routes, there will inevitably be periods, during the time which the signals are normally in operation, when a red signal will hold up approaching traffic although there is no vehicle to use the corresponding green right of way on the cross-road. If the total cycle is as short as may

be consistent with the safety of pedestrians requiring to cross the carriageways, any loss of time by the occasional enforced wait will not be substantially greater than the loss of time associated with the more expensive vehicle-actuated apparatus. It is not realized that police control often causes longer delays to traffic than do the automatic systems.

It was argued that the fixed-time cycle system would result in the red signal being ignored and automatic signalling falling into disrepute. The remedy for this appears to be to enforce the law on persons who disregard the signals just as other laws are enforced on those who disregard them. It is argued further that intersections controlled by fixed-time cycle apparatus will be avoided by motorists, who will seek out alternative routes that are not controlled and more accidents will happen. In some cases it will be advantageous to encourage the use of alternative routes and so relieve more congested intersections.

There is no doubt that where a fixed-time cycle system would result in substantial unnecessary delay, as for instance where in one road the flow of traffic is continuous and in the cross-road light and intermittent, a vehicle-actuated system of signals is to be preferred. Whole-hearted advocates of traffic-operated signals are, however, prone to regard the problem solely as one of passing the largest possible number of vehicles through the intersection, and to enable this to be done apparatus is made capable of being so adjusted that right of way may be changed from one road to another in a period of eight seconds or even less. This period, during which a pedestrian is expected to cross the road, is obviously inadequate for some persons, even on a dry carriageway however narrow.

There are several weaknesses underlying traffic control by light signals. *Firstly*, the traffic turning to the left out of the street which has the right of way to do so in opposition to the side-street red light, whilst the main-line green light allows pedestrians to proceed across it.

The disposal of turning traffic is one of difficulty because the timing of any mechanical signal installation is of necessity a compromise between the requirements of safety and the requirements of rapid dispersal of traffic. As stated above, an absolutely clear signal is generally impracticable, and with that in mind it will be realized that consideration for other road users on the one hand and simplicity of the signal system on the other hand are essential to satisfactory results.

The means to be adopted in regard to the disposal of traffic turning left depend on the width of the road from which it turns and of course on the volume of such traffic. Normally, any traffic is allowed to turn left when the near side signal shows green, but it is unavoidable that

pedestrians in the cross-road where the signal is red to vehicles will be exposed to this occasional left-turning traffic.

In situations where there is a relatively large proportion of left-turning vehicles and where there is ample width of carriageway for at least two lines of traffic so that left-turning vehicles can be directed to the near side of the stream (leaving the off side for straight-through traffic) congestion can be relieved by the provision on the left side of the red signal of a green arrow, the illumination of which during the whole or part of the red period allows left-turning traffic to proceed although the straight-on traffic is still held up by the red signal. This must of course add to the risks of the pedestrian and filtering is approved by the Ministry only in rare circumstances.

Traffic turning right may interfere with his movements to such an extent as to hold him up indefinitely when desiring to cross the street.

Secondly, the *amber light* has not always the respect paid to it that it should have. Between the green and red it often serves as a stimulant to beat the signals by acceleration, to the disturbance of the other traffic. Again, much danger is caused to the pedestrian by the violation of the amber light between the red and green. Too often the traffic begins to move on the appearance of this light and is half-way or even the whole way across the width of the side street before the green appears. As a result the pedestrian, crossing the road, is chased sideways although he is entitled to regard himself as protected during this period. Even when the traffic behaves properly the troubles of the crossing pedestrian persist through the period of the amber light being limited to 3 secs. He may start to cross the road on the last moment of green, not noticing change to orange owing to his attention being taken up in avoiding collisions with other crossing pedestrians. The 3 secs. is the time required for him to reach well into the carriageway, when the traffic is loosed on to him. In certain cases, however, the motorist may be prosecuted for disobeying the signals as being guilty of Careless Driving. The pedestrian's safety might be better assured by placing the stop line farther back from the side street than is usual. This may cause a prolongation of the cycle that is undesirable in traffic control, but some such concession may have to be made to the pedestrian.

An experiment was made in London (following trials in America) to replace the amber light by a red light of the same period, but it was abandoned for the normal three-light cycle ^{33a}.

Thirdly, it has been suggested that the *colour-blind driver* is at a disadvantage, and that for his assistance the red and green lights bear a horizontal and vertical bar; or by the lights themselves being of these shapes. It is difficult to see the advantage of this; so long

as the driver is not illiterate or blind he can read the simple word 'Stop' at present on the lenses, and can quickly learn the relative positions of the lights.

There are three methods of helping pedestrians that can be incorporated in any system of signals whether fixed time or vehicle actuated. These are :

- (i) A pedestrian push-button control (see p. 312).
- (ii) The method of giving an all-red period so that at pre-determined intervals all vehicular traffic is held up on each road simultaneously to enable pedestrians to cross the intersection. This may involve some congestion at certain points, as already pointed out, but it is a concession for the benefit of the pedestrian that should be made.
- (iii) Pedestrian signals may be installed having red and green lights only, bearing the words DON'T CROSS and CROSS NOW respectively, but the latter is open to the objection that it may appear to guarantee safe passage.

Co-ordinating Traffic Signals.⁴² There are four systems controlling movement along and into streets :

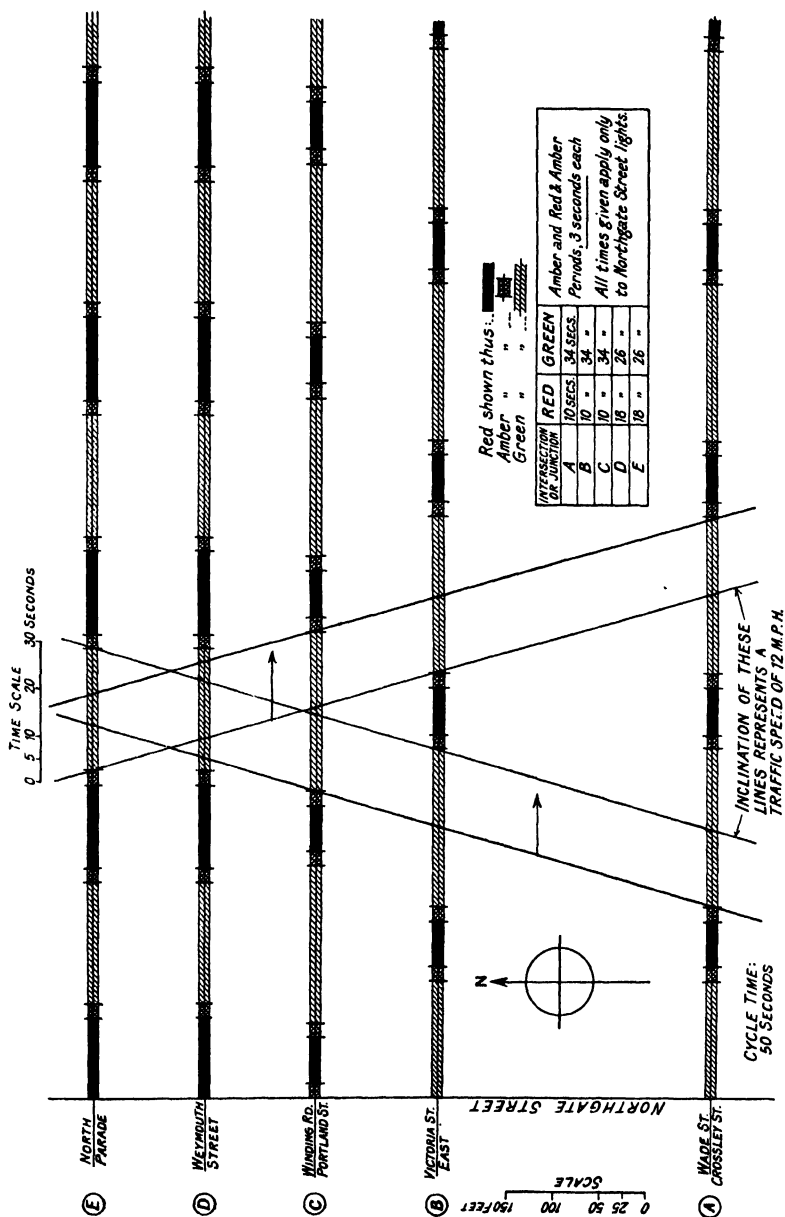
- (a) the Synchronous,
- (b) the Limited Progressive,
- (c) the Flexible Progressive, and
- (d) the Red-Overlap systems.

(a) **The Synchronous System.** At all intersections along the whole street the signals are alike in colour at any one moment, and all change together. This method is only suitable on the rare occasions when the intersections are at regular intervals and the cross traffic is approximately equal to the main traffic. Such a system encourages fast driving, as motorists want to pass as many signals as possible before being held up.

(b) **The Limited Progressive System.** The signals at the road intersections alternate down the street, the effect of which is to divide it into sections of length of every two cross streets instead of every one as in the first method. In this way there is a chance of presenting a continuous series of green lights to correctly moving traffic, but this is only suitable to conditions suited also to the Synchronous system.

(c) There are two main types of the **Progressive System**. The *Fixed Time Progressive* system consists in a number of local controllers which are linked together with a master controller in such a way that the double stream of main traffic and the double stream of side-street traffic flow smoothly according to an assumed rate of travel.

This was found to be uneconomical in time, as the cycle of light-changes was repeated automatically whether the side streets were



By the courtesy of Messrs. CHAMBER BROS., Ltd., and the Borough Engineer of Halifax.

Fig. IX.13.—Example of Grid Diagram for Timing Control Signals according to Traffic Conditions, for Flexible-Progressive Working.

busy or not, or whether the speed of the traffic varied from the assumed value.

Therefore, the *Flexible Progressive* system was devised. This is operated by the vehicles themselves, through contact pads in the road surface, whereby approaching traffic is given time of transit in proportion to the relative number of vehicles present and according to precedence of the first arrival. This is a very simple outline of a brilliantly conceived and developed electrical control of the continual changes in bulk and time of the traffic of many intersections (in one case over 70), together with astonishing constructional handicraft. (An excellent account of the subject is that of T. P. Preist, Traffic Signal Engineer, Automatic Telephone and Electric Co., Ltd.)

The basic phenomenon on which this system is based is a tube, vaguely like a wireless valve, containing neon or a mixture of neon and argon, at a particular very low pressure. The property of such a tube is that no electric current will pass through it if the applied voltage is below a certain value. When it has risen above this, the gas becomes ionized, the insulation breaks down, and a current passes so long as the voltage is maintained : if it falls, insulation is re-established and the current stops.

This is applied to traffic regulation, by each vehicle, passing over a detector pad in the road and making contact in it, sending a ' pulse ' consisting of a relatively small charge into a condenser. When sufficient of such charges have accumulated to raise the voltage above the insulation value of the tube, a current passes which actuates relays and works the lights.

By this method, the resulting traffic streams are much more regular, and the total quantity passed is greater. Abnormally fast driving only results in frequent stops.

(d) The **Red Overlap System** of timing signals is devised to allow the crossing of a stream of traffic with the minimum of disturbance to the rest.

In the case illustrated (Fig. IX.14), the red light is continued for a short while at 1 and 3 after the green has come on at 2 and 4 to enable vehicles to pass out of the line BC into the side road towards D without interference from vehicles coming from A, which normally would be flowing at the same time as the BC traffic. One disadvantage of this is, however, that a pedestrian at F, seeing a red light at 3 and thinking it is safe to cross to E, may be caught by the flow of traffic from B.

In the **vehicle-controlled system**, instead of a prearranged setting of the timing switches, the cycle of operations is controlled as required by the traffic passing over detector pads set in the road

surface which are in electrical or pneumatic connection with the controller. In this way there is the minimum of delay in the passage of both streams of traffic, as the controller not only produces the same result as the other systems, but also takes cognizance of the time and speed of arrival of the approaching vehicles of both streams and allows the passage in the best order and at the best moment. It is obvious that this system shows to the greatest advantage when the traffic is of irregular quantity and there is considerable variation between the streams. One of the most notable and successful installations is that which controls the complicated traffic round Trafalgar Square, London, and this is worthy of study ³²⁵. This system can be made to change to the Flexible Progressive system at periods of peak load, when the latter may be more suitable, and to change back at a predetermined time.

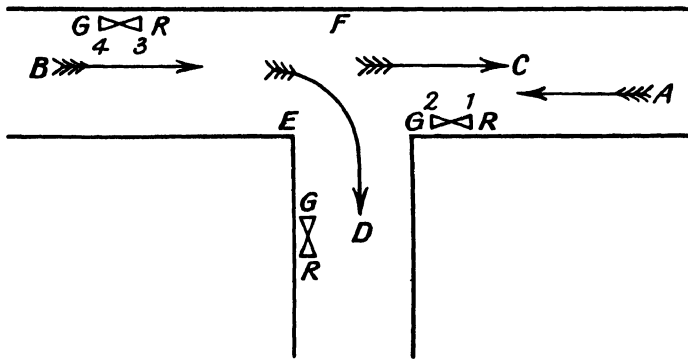


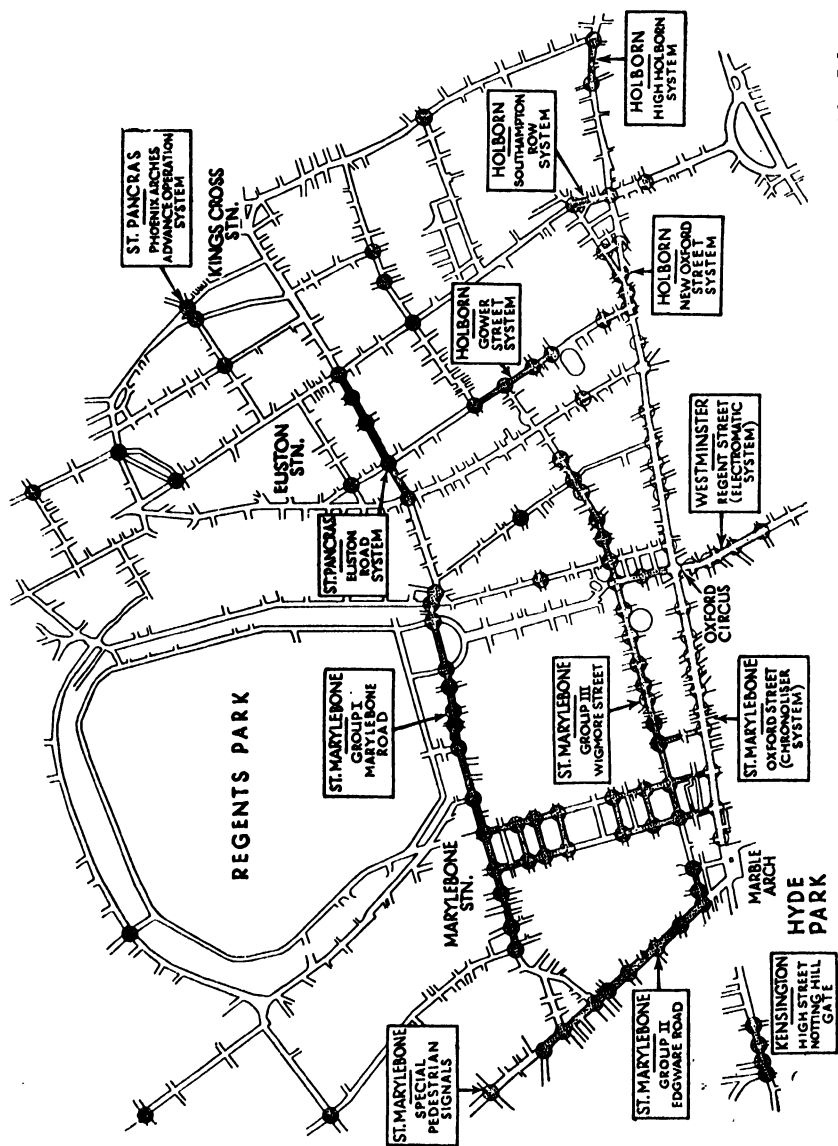
FIG. IX.14.—Red Overlap System.

The heart and brain of all these systems is the Controller, of which the simplicity of adjustment and limits of time-action are laid down in the British Standard Specification (505 : 1939). The switches may be of the usual construction or of the mercury gas-filled type.

The *vehicle-operated* controller is quite different from the above, being operated by the successive charging of a condenser by the passage of vehicles over pneumatic road contacts, and discharging through a special gas-filled valve which controls the light signals.

Development and elimination have led to an extension of control that is astonishing. Not only can the master control vary the cycle time according to the quantity of traffic which changes with the time of day, but also working can be established between various systems of control, as is shown in the great complex which operates in the west end of London (Fig. IX.15).

Complexity of another kind has brought order out of near-chaos



By the courtesy of the Siemens & General Electric Railway Signal Co., Ltd.

FIG. IX.15.—Interlinking of Traffic Control Systems.

at the junction of six streets at the Bank (London) ; and a description of this achievement by the Automatic Telephone and Electric Co., Ltd., follows.

The name ' Bank Complex ' has been given to the area which is the junction of Threadneedle Street, Cornhill, Lombard Street, King William Street, Princes Street, Queen Victoria Street, Poultry, and Mansion House Street.

A specification for traffic signals to control the heavy and complicated traffic at this junction was prepared by the Ministry of Transport in collaboration with traffic officials of the City of London Police, and a control system to meet the requirements of the specification was designed by Automatic Telephone & Electric Co., Ltd., using Electro-matic vehicle-actuated signals (Figs. IX.16 and IX.17).

The signals will operate on a plan which in the first place ensures efficient control at the ' Complex.' A further feature of the plan is that, in addition, other junctions in the immediate vicinity will be controlled by the same master timer, to ensure free flow of traffic to and from the ' Complex.' Major interest in the new installation, however, centres on the ' Complex ' and some details of the method of operation will be of interest.

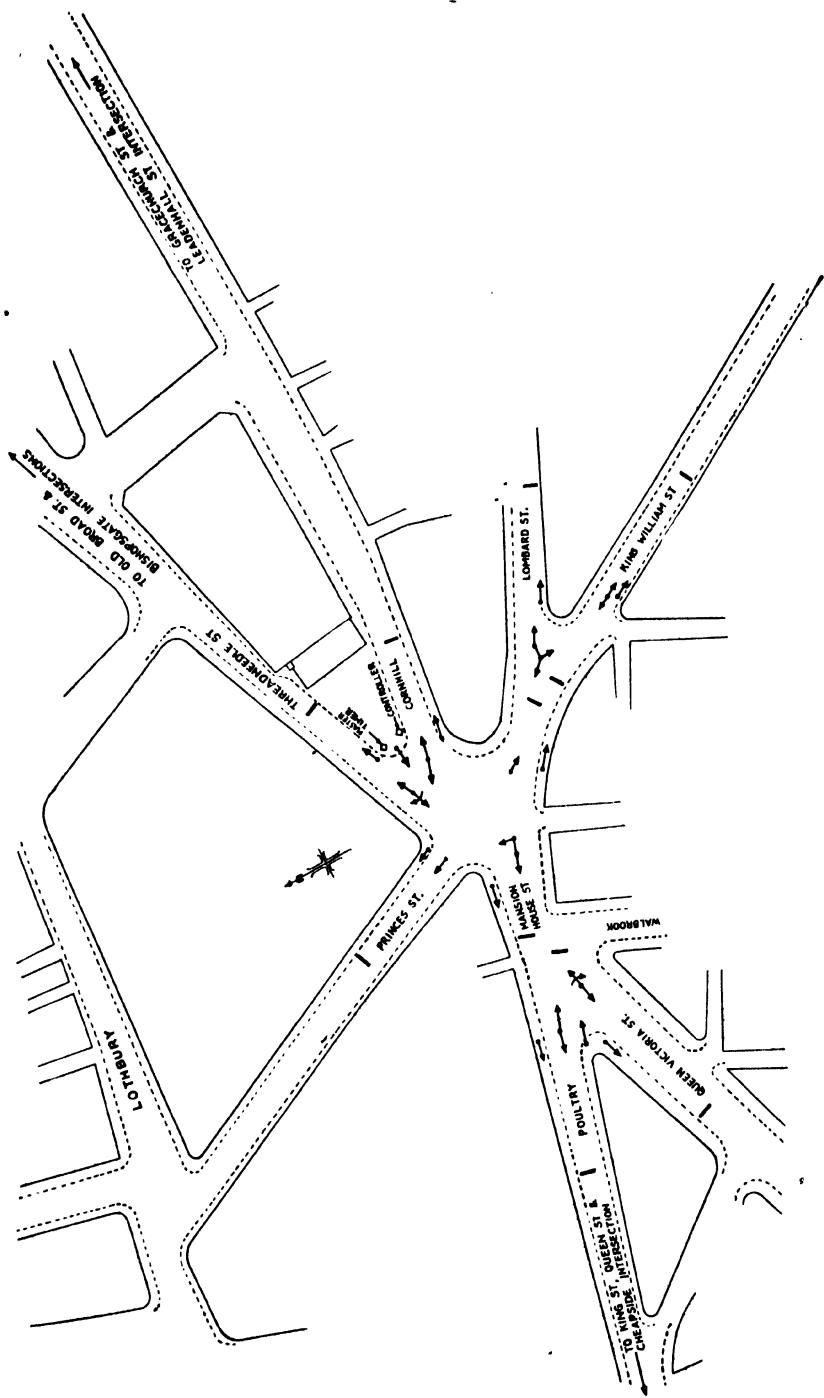
Drawing No. 1 is a plan of the ' Bank Complex ' and shows the positions of the traffic signals. From the drawing the difficult and complex layout of the junction will also be appreciated, particularly when it is realized that no less than 35,000 vehicles use the junction each 12 hours and that most of the approaches are narrow. The actual figures for the various approaches in the 1939 census were :

King William and Lombard Street	.	.	.	.	.	5,833
Princes Street	.	.	.	.	.	5,545
Poultry	.	.	.	.	.	7,408
Queen Victoria Street	.	.	.	.	.	5,839
Cornhill	.	.	.	.	.	5,048
Threadneedle Street	.	.	.	.	.	5,429

To deal with this heavy volume it has been arranged that traffic will flow in four stages as shown in Drawing No. 2.

The general principle of allowing east- and west-bound traffic to flow and then permitting the north- and south-bound to move has been followed, as will be seen from the sketches. The four main stages of the traffic movement are as follows :

Stage 1. Traffic flows through Queen Victoria Street and Threadneedle Street, but vehicles in either of these streams wishing to turn off to Cornhill or to Poultry are temporarily ' held ' ; otherwise they would have to cross the traffic stream, which would be dangerous. Cross-traffic from Princes Street and King William Street is held for

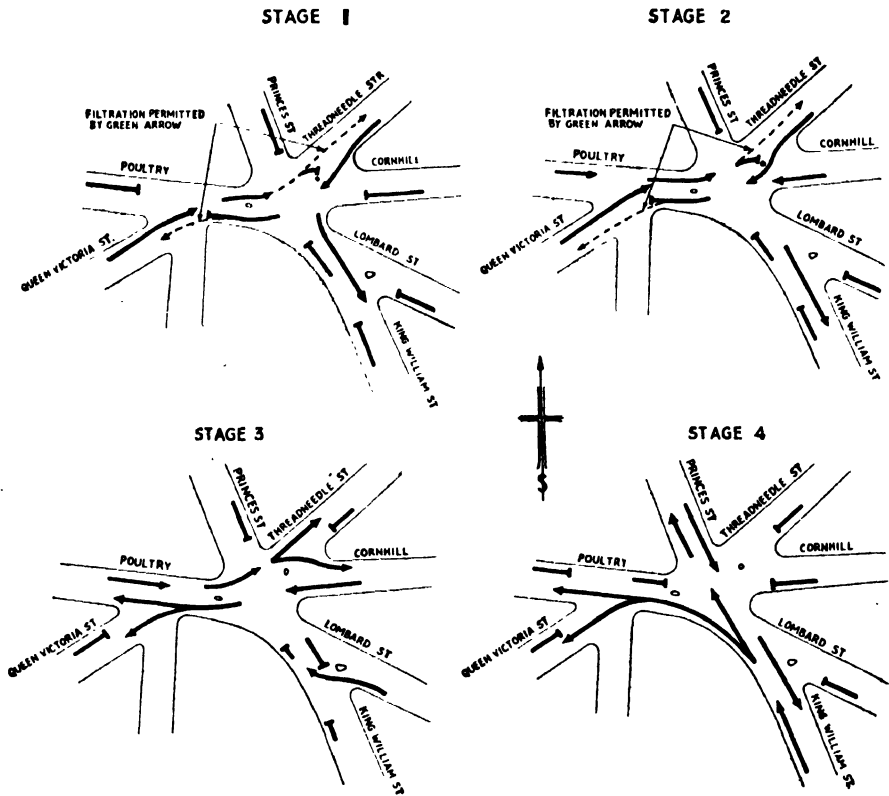


By the courtesy of the Automatic Telephone & Electric Co., Ltd.

Fig. IX.16.—Main Signals—'Bank Complex.'

the same reason. Traffic from Poultry and Cornhill is also held until the head of the line of vehicles from Queen Victoria Street and Threadneedle Street has passed.

Stage 2. Traffic from Poultry and Cornhill now joins in, but traffic wishing to turn into Cornhill and into Poultry is still temporarily held to avoid crossing the main stream. An ingenious traffic assessing device is associated with the Poultry and Cornhill signals. Its purpose



By the courtesy of the Automatic Telephone & Electric Co., Ltd.

FIG. IX.17.—Main Stages of Operation at the 'Bank Complex.'

is to count the density of vehicles in Poultry and Cornhill, and should this be over a certain prearranged maximum these streams of traffic will be released earlier in the cycle to permit a longer period in which they can be cleared. The extent to which the Poultry and Cornhill traffic is overlapped with that of Queen Victoria Street and Threadneedle Street is therefore a variable, dependent upon the action of the traffic assessors.

Stage 3. Traffic now flows from Poultry across to Threadneedle

Street and Cornhill ; and from Cornhill to Poultry and Queen Victoria Street. Outgoing traffic from Queen Victoria Street and Threadneedle Street is held to avoid crossing the main streams which are flowing. At this stage traffic is permitted to flow out from Lombard Street, but is temporarily held a little farther on.

Stage 4. North and south traffic from King William Street and Princes Street is now allowed to flow with the east- and west-bound traffic held. Traffic from King William Street also flows into Queen Victoria Street and Poultry, vehicles from all the other roads being stopped.

In addition to the main stages detailed above, there are a number of so-called minor stages. Although usually termed the minor stages each of these is very important in enabling the maximum efficiency to be obtained from the system as a whole. These minor stages are as follows :

Minor Movements during Stage 1.

Traffic from Queen Victoria Street is given a short lead of approximately 3 seconds before the traffic from Threadneedle Street and Mansion House Street (eastbound) is released, so as to take advantage of an 'all-red' clearance period which follows Stage 4.

Green arrows are provided to permit filtration of traffic into Threadneedle Street (eastbound) and into Queen Victoria Street (westbound).

It may also be noted here that if there is no demand for right-of-way from Threadneedle Street the right-of-way may be taken by Cornhill. Similarly, if there is no demand from Queen Victoria Street right-of-way may be taken by Poultry and if this does occur neither Queen Victoria Street nor Threadneedle Street is permitted to take right-of-way during the particular cycle of signals.

Minor Movements during Stages 1 and 2.

The green arrow signals for traffic filtration into Threadneedle Street and Queen Victoria Street continue throughout Stages 1 and 2. They are not required during Stages 3 and 4, as the main green signal would then be showing.

Minor Movements for Stage 4.

At the beginning of this stage an 'all-red' period is introduced to clear the intersection of east-west traffic before north-south traffic is released.

Similarly, an 'all-red' period at the end of the stage permits clearance of north-south traffic before east-west traffic is released,

but in this case an exception is made in favour of traffic entering from Queen Victoria Street as detailed in minor movements during Stage 1.

The whole system will be 'Electro-matic vehicle-actuated,' operating on the 'flexible-progressive' principle under the control of a dual-master-timer. Vehicle detectors will be used in each approach to the 'Bank Complex.'

The signals themselves are actuated by a special control unit divided into seven sections which are linked together to co-ordinate the signal phases.

The seven sections are associated respectively with signals for :

- A. Traffic from Threadneedle Street and traffic into Cornhill.
- B. Traffic from Cornhill.
- C. Traffic from Lombard Street and traffic into King William Street.
- D. Traffic from King William Street.
- E. Traffic from Princes Street, Lombard Street at Mansion House Street and traffic east-bound in Mansion House Street.
- F. Traffic from Queen Victoria Street and traffic into Poultry.
- G. Traffic from Poultry.

It is important to note that right-of-way is given to an approach only if there is a demand, and the length of this right-of-way period depends, up to a predetermined maximum, on the volume of the traffic. Right-of-way is offered to each approach in a definite sequence, and according to a progressive plan by means of a master-timer which sends out timed pulses to maintain strictly the cycle of operations.

Special arrangements are made whereby in certain cases right-of-way time not used by one approach during any cycle may be used by a second approach. The pairs of approaches having this facility are :

Threadneedle Street and Cornhill.

Queen Victoria Street and Poultry.

Lombard Street and King William Street.

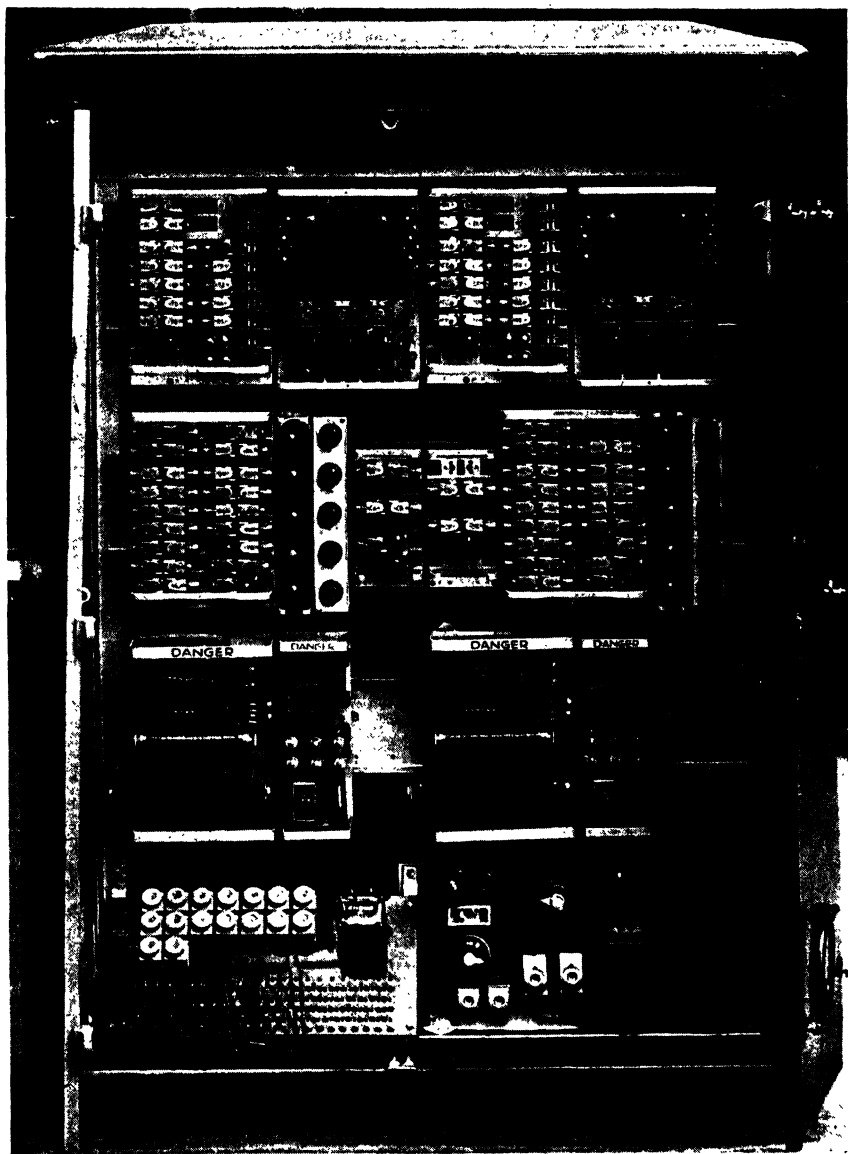
As already stated, if there is no demand on Threadneedle Street, then traffic on Cornhill is permitted to have right-of-way during the time which was allotted to Threadneedle Street and can retain right-of-way for the whole length of the two periods provided for these two approaches in the cycle. Similar conditions apply to each pair.

Whilst narrow roads and lack of 'reservoir' space—that is space which can be occupied by waiting traffic—are two of the reasons for the heavy traffic demands at the 'Bank Complex,' a third point of great importance is that the intersection is in the line of several main traffic routes running east and west and also north and south through

the City of London. For this reason the most recent 'Electro-matic' signal development, known as 'Biassed Linking,' has been applied to link the 'Bank Complex' with several adjacent intersections, and thus form one complete scheme. The other intersections which are to be linked up at once with the 'Complex' are (a) Threadneedle Street and Old Broad Street; (b) Threadneedle Street and Bishopsgate and (c) Princes Street and Lothbury. At a later date it is also proposed to link-up the intersections of (d) Cornhill and Bishopsgate and (e) Cheapside and Queen Street. The intersections (c) and (e) are already individually controlled by 'Electro-matic' signals and, to link-up on the 'Biassed Linking' principle, all that will be required will be to change the two controllers.

The operating principles of 'Electro-matic' 'Biassed Linking' will doubtless be gathered from the following outline description. Precisely as in ordinary 'Electro-matic' control, vehicles receive individual 'consideration' by means of the road detector and the controlling mechanism, but, in addition, a special reservation is introduced into the timing which can best be described as a 'right-to-priority' period. This special period is introduced into the timing by means of the master-timer for the benefit of vehicles flowing along the main road or over a prearranged through-traffic route; or it can best be described as a period during which normal traffic control is in operation but during which the particular through traffic has a special 'priority right' to the 'green' signal and can thus temporarily over-ride the claims of cross-road vehicles which would otherwise cause delay. The priority period is introduced into the timing cycle at each intersection, and it is introduced in successive stages of the timing according to the progressive plan.

The following is a brief explanation of the method of 'Biassed Linking' operation. If a vehicle or block of vehicles arrives at an intersection when the signal is showing 'green,' no delay is encountered at the particular intersection. Now, in the usual co-ordinated system involving a number of intersections, it may happen that traffic having crossed one intersection encounters the 'red' signal at the next. With 'Biassed Linking,' however, the timing is so arranged that if each traffic-group is travelling at the correct speed, it will arrive at each successive intersection within the 'right-to-priority' period and so immediately secure the 'green' signal. As this special period is introduced only as one section of the complete cycle of timing there is no undue penalizing of cross-traffic, and the highly important result is achieved of one or more blocks of main-line traffic moving at a constant speed without interruption or delay at any of the intersecting roads.

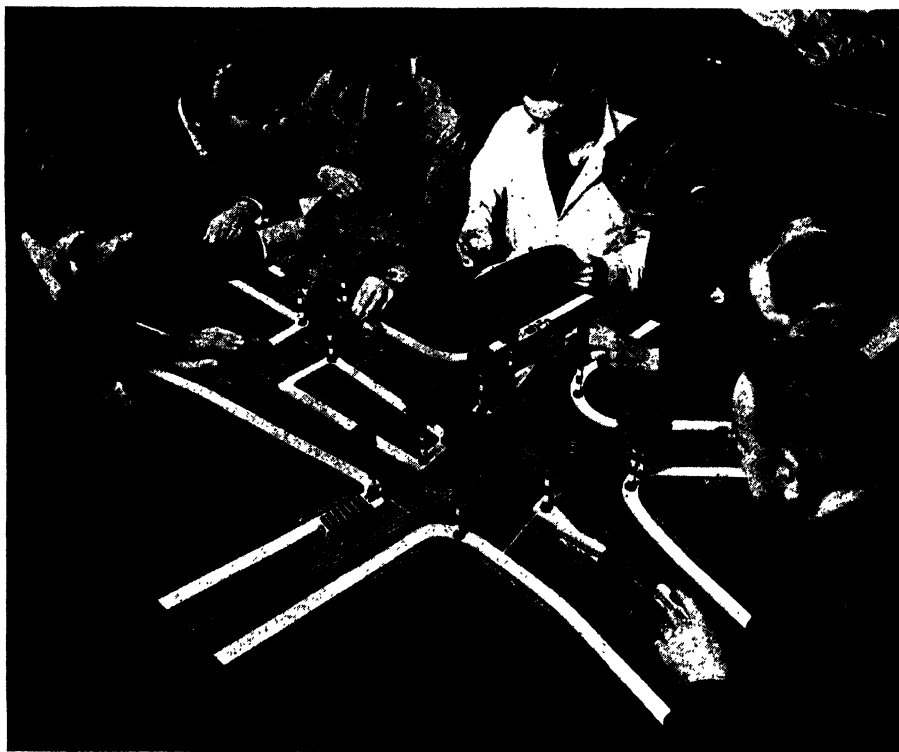


By the courtesy of the Siemens & General Electric Railway Signal Co., Ltd.

FIG. IX.18.—Autoflex Master-Controller, front view, equipment covers removed.

The type of master-control that makes such results possible is seen in Fig. IX.18. The complete installation is in duplicate, so that if failure should occur in one working section, the other is automatically switched in.

Some idea of the care that is given to the study of a new problem can be gathered from the work shown in Fig. IX.19.



By the courtesy of the Siemens & General Electric Railway Signal Co., Ltd.

FIG. IX.19.—Scheme for the 'Elephant and Castle' Crossing. Experts considering Timing of Intricate Traffic Movement.

Another variation that has been adopted to a limited degree is the **hand-control** system operated by the pedestrian. A push-button causes the red light to be shown to the traffic and a green one to the pedestrian, generally giving the latter 15 secs. for safe crossing. Continuous pressure on the button does not prolong unduly this period, nor can the signal be repeated before the expiration of a given period.

There is indecision among authorities as to whether the public should be given the power to interfere with the traffic flow which, at any one point, is an integral part of the major problem of passing

traffic along a street with the minimum of delay. In some positions it is successfully used, and during the last 15 years or more many cities have adopted the system ; it is particularly valuable opposite schools.

The scheme ³⁹³

Red : 10 secs. ' CROSS NOW '
Green : 20 ,, ' DON'T CROSS '

has been found to be suitable.

An interesting system of **combined rail and road control** automatically enables all road signals to turn to red and the railway signals to green on the approach of a train, and these all resume normal working after the train has passed ³⁹³.

Temporary traffic control can be effected by some form of portable installation.

The *types and positions of the Signals* must be selected to give the driver and the pedestrian the clearest possible directions as to their movements ; these may be 1-, 2-, 3-, or 4-way. They may be erected as separate standards (which themselves must be made clearly visible by being painted with broad black and white stripes as required by the Ministry of Transport), fixed to walls of buildings, or suspended overhead across the street, or mounted on pedestals. It is desirable that there should be the possibility of at least two signals being visible from each stopping point in case one is obscured by any cause.

Care must be taken that the signal lights are not confused by other lights—a serious matter in some places.

Signal head assemblies should be erected with at least 15 in. clearance between the side of the casing and the edge of the kerb, with the middle of the green roundel 7 ft. 6 in. above ground. This height may have to be raised to clear obstructing shop blinds, but it is better to adhere to the lower height and to have the blinds cut back when possible. Cable tubes of 2–3 in. diameter gas barrel or 4 in. diameter stoneware pipes should be laid under the carriageway to receive the inter-connecting cable. Provision should be made for any subsequent linking up of a number of sets by laying a spare tube to avoid opening up the carriageway again. A spare circuit added to the number of circuits required for operating the sets should also be laid. This may be useful at a later date if any alteration of the light sequence is decided upon, such as a split amber period. In the rare event of the signals being strung across the street, they should be at least 16 ft. 6 in. clear of the roadway. The beam of light should be directed on to the traffic at a distance of about 150 ft., allowance being made for the gradient of the road.

There is an intimate connection between the position of the signals, the corners of the road intersections, and the position of the (*white*) *stop line* at which the traffic must stop. It is important that stop lines should not be further apart than is necessary, so that the time occupied by vehicles in clearing a crossing should be as short as practicable. At the same time, care should be taken to keep the stop lines sufficiently far back from their respective signals to enable drivers to obtain a clear view of the signal. Saloon cars with comparatively low roofs obstruct the view of the driver when the car is close up to the signal post or when the lights are fixed at a high level. The pedestrian would be safe-guarded by the line being set far back, when the traffic starts on the amber light.

The police in the Metropolis like 'Stop' lines placed as near to the primary signals as practicable and are generally placed 6-7 ft. behind the post. These in every instance should extend to the centre of the road. In roads which have no tram tracks a white line is put down longitudinally for a distance of 40-50 ft. With traffic-actuated system a second line starting at the detector pad and extending 20 ft. back from the intersection is necessary to guide traffic on to pad.

In some cases it may be desirable that *Warning Signs* of approach to automatic signals should be erected, but the Ministry of Transport discourages the installation of these signs, except under special conditions.

The *illuminating system* is contained in a signal head of aluminium alloy—containing not less than 5 per cent. of silicon—unless otherwise agreed, fixed or adjustable as may be required by local conditions, in which the three lenses, of 8 (or unofficially) 12 in. diameter, are separately lighted. The source of illumination is electric lamps of 60 watts, which are assumed to be sufficiently powerful to render the signal effective in sunlight at a distance of 300 ft. The lenses may be simple and supplied with some means of diffusion and chromium- or silver-plated parabolic mirrors. The spread of light horizontally should be at least 80° and at an angle at least of 45° below the horizontal. It is of primary importance that the signals should be strikingly obvious to the traffic, rather than having a scientifically optical perfection.

All lens holders should be hinged, otherwise it may be necessary to make six trips up and down a ladder when changing a lamp. Those that are hinged should be handed so that they open towards the back of the footway. This also applies to doors of controller cabinets and other covers to openings.

Visors are fixed to restrict visibility to the traffic they are intended to control, and also to prevent the lenses from being affected by the rays of the sun or other external light sources. (See also ¹⁸².)

Improvements to the benefit of the motorist and the pedestrian relying on the direction of traffic control signals are still possible. For instance, the efficiency of the signals at many crossings is not as high as it should be owing to the presence of bus and tram stops. It is irritating to a road user about to proceed on the green signal to be baulked by passengers boarding and alighting from buses and trams. This could be obviated to a great extent by making all bus and tram stops outside a controlled area of, say, 150 ft. from the signals with a minimum distance of 50 ft. between tram and bus stops. Congestion is also caused by buses and trams making a busy crossing their termini. Once traffic signals are installed they should never be turned off except at night or in case of a breakdown.

Maintenance. Traffic signal apparatus on the public highway is required to operate under very trying conditions. Considerable changes of temperature, hygroscopic variations, unclean deposits from the air, and heavy vibrations from passing traffic necessitate constant attention. Screws or nuts may become loosened and lamps may become loose in their holders.

All apparatus should be robust enough to function for periods of many months without needing adjustment or any technical attention to the control mechanism. Condensation of moisture within the casing is often serious, and special care should be taken to protect the apparatus—particularly the electrical parts—from its effects. All connections should be well taped. The risk of trouble from this cause is less when the apparatus operates continuously.

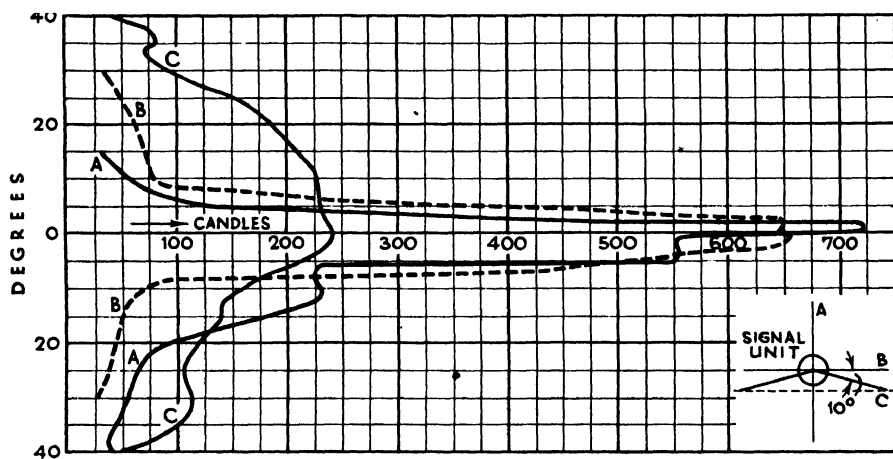
The majority of defects in operation are simple and easily put right ; in order of importance and frequency :

- (1) Lamps with broken or burnt out filaments.
- (2) Faulty adjustment of time switches.
- (3) Unclean contacts (due sometimes to excess of lubrication, no lubrication, or sparking).
- (4) Sticking movements.

Unless the system can be relied upon to operate accurately and continuously it may be worse than useless.

The possibility of a breakdown of a controller of good design and workmanship is remote and, unless anything serious happened, can easily be put right on the site by someone with a sound knowledge of the working of the controller. A council possessing not less than about twenty-five sets should reduce expenditure considerably, expedite repairs, and maintain a higher standard of efficiency, by undertaking the maintenance of the sets themselves. In addition to special adjustment and repairs which require more or less technical skill, the lamps should be visited at least once a week for cleaning, setting time switch,

attending to lamps, oiling, etc., and the person who does this should be at least capable of minor repairs. The changing of lamps is a factor of considerable importance; cases are known where a lamp at one intersection has required changing on three consecutive days. Although a life of 800 hours may be allowed (allowing the remaining 200 hours to set off against the large number of times which the lights come on and off each day—between 1,250 and 1,750 times at some intersections) it will be found that after 500 hours breakages occur. Invariably the filaments are not sagged but have broken, probably due to traffic vibration. In order to avoid confusion of traffic due to



By the courtesy of the Siemens & General Electric Railway Signal Co., Ltd.

FIG. 1X.20.—Photometric Curves showing Distribution of Light from D5/3705 Signal
Curves based on I.T.T.E.L. Curves.

CURVE A : In a Vertical Plane bisecting the Unit.
CURVE B : In a Horizontal Plane bisecting the Unit.
CURVE C : In Various Directions approximately 10° below Main Beam.

failure of an electric lamp, these should be replaced every 700 or 800 hours, and their remaining life utilized in some less important positions.

Designers of signal apparatus are primarily concerned with electrical, mechanical and optical efficiency, and such matters as obstruction of the public way does not often occur to them. For example, the bases of some controller cabinets are so wide as to make it impracticable to locate them on a footway of normal width without unjustifiable obstruction. Other controller cabinets are no more than 9 in. square and are therefore far more suitable for installation near the kerb.

At the same time, the space available for fuse box, time switch (when required), etc., must be adequate and afford convenient access ;

this is of the utmost importance, as adjustments and replacements may be necessary during wet weather.

If space or circumstances permit, the controller would be better placed on the back of or off the footpath with all the signal head assemblies mounted on separate posts either near the kerb or on brackets projecting over the footway. The controller in this position would be less liable to damage by collision and less affected by traffic vibration. Obstruction by controller cabinets is reduced in those cases when they form part of the signal post.

Traffic signal lamps are generally of the 60-watt vacuum rough service type. They are made with bayonet joints or with Edison screw joints and with light centres of 64 or 85 mm. This dimension is the distance between the outer contact of the lamp and the centre of the filament, and the reflecting or optical system in the signal head is made so that with a lamp of the correct light centre the filament is at the focal point of the reflecting or optical system. Working conditions are such that the guaranteed life of 1,000 hours is rarely obtained and even when the lamps are changed after 800 hours use it is found that towards the end of that period failures are more frequent than is desirable having regard to the expense involved in sending out at short notice to replace a lamp that probably cost less than two shillings in the first place. Economy of maintenance would result if a really robust and reliable lamp could be obtained at even double the present initial cost. Apart from possible defects in the lamps themselves there are three factors that are conducive to lamp failure : (a) excessive vibration, which can be met to a certain extent by anti-vibration lamp holders ; (b) the use of lamps rated at or below the normal line voltage of the supply mains. Variation of voltage that is allowed by Statute must also be kept in mind.

When replacing lamps it is very important to see that the dimension of the light centre is suitable for the lamp head, otherwise, as stated above, the centre of illumination will not coincide with the focal point of the reflecting system and inefficient illumination will result. It is not the practice at present to mark on the lamps or even on the cartons the dimension of the lamp centre, with a result that it is not easy for a maintenance man to be sure in poor light that any one lamp is of the required dimensions unless he has both sizes available at the time for comparison. A millimetre rule cannot be read easily at night under semi-dark conditions. Some effective means of identification are urgently required, but in the meantime maintenance men should be provided with a simple form of gauge for this purpose.

Finally there is (c) the great frequency of switching on and off.

Installations at Boundaries of Districts or in More than One Area of Electrical Supply.

Installations of traffic signals overlapping the boundaries of local authorities present several aspects that require early investigation and settlement; otherwise they may lead to delay and unnecessary expense at later stages of the work. Similar difficulties present themselves at boundaries between the areas supplied by different electrical undertakings employing alternating and direct current respectively, or of various voltage.

After the scheme of signals has been decided the first point to settle is the position of the controller. Normally, in cases such as the above, the electrical undertaking in whose area the controller is placed would supply the current; but where one or more of the signals will be situated within the supply area of an adjacent undertaking, arrangements must be made at an early stage for any necessary sanctions authorizing the supply of current to lamps outside the area of the undertaking affording the supply and the charges for such current settled.

It may happen, further, that the characteristics of the supply by the undertaking in which the controller is situated may not be so convenient as those of an adjoining undertaking so far as the efficiency of the signal apparatus is concerned. For instance, in certain types of apparatus it is desirable to step-up or step-down the main supply voltages for working certain parts of the control apparatus. In this and other cases alternating current is generally more convenient than direct current for operating the traffic signal controllers. Although most of the manufacturers make apparatus that will function satisfactorily on either alternating or direct current, the cost may be higher in one case than in the other.

In a recent case of a joint scheme where the supply was alternating on one side of the boundary and direct on the other, one authority advocated a duplicate supply of current to be available in case of breakdown. The proposal would have involved either converting the direct current to alternating current so as to have the controller working on that more convenient type of supply, or having two controllers, one in the direct supply area and the other in the area of alternating supply. With the former it would of course be essential that the characteristics of the locally converted direct current should be precisely similar to those of the alternating supply from the mains in the adjacent area, otherwise the timing of the signals might be seriously affected. In either event the proposal involved an extra cost of about a hundred pounds, which was considered to be out of all pro-

portion to any advantage likely to result from the duplication of the supply.

A duplicate supply of electricity for signals is very rarely provided, as the risk of a temporary breakdown of supply is far less likely than failure of the signals from some other cause. Moreover, a stoppage of current would result in the whole system ceasing to operate, which might be much less serious than partial failure such, for instance, as one or more individual lamps giving out.

Traffic Signals or Roundabouts ?

The question as to whether the installation of automatic signals or of a roundabout is the more desirable, having regard to the particular circumstances of a road junction, will often have to be decided.

Generally, signals will be less expensive in the first instance but may be more costly to operate and maintain. Normally also, the first cost of a roundabout will be relatively less the greater the number of the roads converging upon the junction.

Lower prices will be approached only when all conditions are favourable. The cost will advance principally as the length of cable and the difficulty of fixing posts and running cable increases. For instance, it is often very expensive to run cables under tramways, particularly when there is a conduit, and reinstatement of the carriage-way may be a costly item. One important factor in respect to which there is considerable doubt, is the life of the apparatus. In many cases it has to withstand much vibration, in addition to which condensation is often serious. Cables, posts, and signal heads should last many years if reasonably well maintained ; lamps, globes, and lenses should be renewed as required as a maintenance charge ; but controllers, time switches, and other electrical and moving parts may, in some cases, require renewal in five or six years. The annual cost of operation, adjustment, cleaning and maintenance may equal 10 per cent. or more of the first cost.

The cost of a roundabout will vary considerably. The minimum diameter of the island should not be less than 70 ft. and should be so designed as effectively to cover the entrance of each road. No curve in the perimeter of the island should be less than 30-ft. radius, but a minimum of 40 ft. is desirable. One of the principal varying factors is the cost of providing the necessary space. Where land would have to be purchased for the purpose, the cost may be prohibitive. Where, however, the existing open space is sufficient and the cost of road works is reasonable, a roundabout may be less expensive than automatic traffic signals, particularly when the number of roads exceeds four,

and the alternative would be traffic-operated signals. Usually, however, the first cost of a roundabout will be more than that of signals, but the annual cost will probably be less. The latter for a roundabout will involve cost of illumination with possibly some extra cost of road maintenance, owing to the greater area of surface and more wearing effect of traffic moving in a circular direction.

At the same time, a roundabout has several advantages for which it is worth paying a rather higher price. The principal one is that the movement of vehicles is continuous and loss of time is almost negligible. As a rough guide it may be assumed that the alternative of a roundabout should have careful consideration when it can be provided at a first cost not exceeding twice that of a traffic signal installation, but in some circumstances it could be justified at a much greater cost.

PART X

ADMINISTRATION AND LAW

I

CENTRAL HIGHWAY ADMINISTRATION

Road administration began in Roman times, and the development from this period to 1939 has been summarized by Sir L. Browett ⁵²⁰.

The department of the Central Government of Great Britain responsible for highway administration is the Ministry of Transport through its Road Department.

This Ministry was constituted by Act of Parliament in 1919, and took over the duties and responsibilities of the Road Board which had been set up in 1909 to administer the *Development and Road Improvement Act* of that year. The Ministry was also invested with powers and obligations beyond those exercised by the Road Board.

Sir Henry Maybury, the Chief Engineer and Manager to the Board, became Director General of Roads in the Ministry, and it is very largely to his genius as an organizer and administrator, his sound judgment, his technical skill, and the universal confidence he inspired, that this country owes the present high standard of highways and highway administration.

In the early days of the Ministry the more important highways of the country were classified under the designation of Class I and Class II roads. In the former class was placed about 26,000 miles and in the latter about 16,000 miles, the balance of about 140,000 miles remaining unclassified. Generally Class I included main national routes, and Class II main routes of a more local character. The practice of taking a triennial traffic census on Class I roads was inaugurated in August, 1922, and later on Class II roads.

From time to time the powers and responsibilities of the Ministry and of local highway authorities have been extended by Parliament. For instance, the Ministry of Transport Act, 1919, empowered the Ministry to contribute towards the salaries of the technical officers of highway authorities, with some control over appointment and dismissal. By the Road Improvement Act, 1925, the Ministry was also given power to conduct research and experimental work, and as an

outcome of this the experimental station at Harmondsworth, Middlesex, was established, and other experimental work undertaken.

Far-reaching alterations in local highway administration were effected by the transfer, under the Local Government Act, 1929, to County Councils, of the highway powers of Rural District Councils and the responsibility for all Classified Roads in Urban Districts other than Metropolitan and County Boroughs ; and later by the passing of the Trunk Roads Act 1936 and 1946.

These Acts provide that, as from April 1st, 1937, the Minister of Transport shall be the highway authority for the principal system of routes for through traffic. Roads within the county of London, and those in county boroughs are excluded. Under the 1936 Act 4,459 miles of highway became Trunk Roads, and an additional 3,685 miles was included under the 1946 Act.

Sec. 5 of the Act authorizes the Minister to delegate to the Council of any county or borough or urban district any of his functions with respect to the maintenance, repair and improvement of and others dealing with any trunk road, and under Sec. 6 he may agree with any such council for the execution by the council of works connected with construction or improvement of any trunk road.

Practically the whole of the maintenance and repair of trunk roads has been delegated by the Minister to the local highway authorities, the whole of the cost being refunded by the Minister.

The main responsibility for highway administration, therefore, still rests with local highway authorities with the guidance and help of the Ministry. There is cordial co-operation between the central road department and local authorities and it is rare to find them at serious variance. The Ministry is assisted by various advisory bodies, such as the Technical Advisory Committee and the London and Home Counties Advisory Committee and the Transport Advisory Council.

The control exercised by the Ministry in respect of Classified Roads arises mainly in connection with grants made to highway authorities from the Road Fund. Originally a grant of 50 per cent. of the annual cost was made towards the expenditure of highway authorities upon Class I roads and of 25 per cent. towards Class II roads, but later these were increased to 60 per cent. and 50 per cent. respectively.

Under the Local Government Act, 1929, the basis of contributions by the Government to Metropolitan Boroughs, County Boroughs, and large Scottish Boroughs was altered, and all grants for routine services were merged with ' block grants,' calculated on a special formula.

Approved special expenditure, including major improvements, and new features, such as automatic road traffic signals, are still dealt with upon a percentage basis.

Grants towards scheduled unclassified roads (or rural roads in counties) were first made in 1926, but these also are merged in the block grants.

Within the limits imposed upon it by Parliament, the Ministry of (War) Transport has worked with the conscientiousness that is expected of a government organization. But criticism of lack of vision and an unscientific—or, rather, non-scientific—approach to the solution of traffic problems has been growing among progressive minds. This has led to a constructive suggestion for a New Highway Authority ⁵²⁸ in order to get safer, freer, and speedier transport. One of the most prominent of these critics is Lieut.-Col. Mervyn O'Gorman who desires :

(1) All traffic activities to be placed under a skilled Permanent Director, answerable to Parliament ;

(2) A Highway Board, to act as advisor, being composed of representatives of all sections of road users and planners ;

(3) A Research Committee of Traffic Flow, to be provided with required information by the Director.

This is included in an important Memorandum from the chief motorist organizations of the country ^{528b}.

Parliament keeps itself closely informed on road matters through Road Groups in both Houses.

II

LOCAL ADMINISTRATION

The subject of administration in its relation to a municipal engineer's department, generally, has already been dealt with in a book ⁴¹³ by one of the Authors, which was revised in a second edition. It is proposed therefore on this occasion, merely to supplement the information given in that volume, with some further particulars relative to highway administration principally in connection with the work of county highway authorities.

Contributions from the central government towards the cost of maintenance of Class I and II roads in the case of County Boroughs and Metropolitan Boroughs are included in a ' block grant ' covering contributions to a number of local government services. Contributions towards the cost of both maintenance and improvement of highways outside these boroughs is still based upon a percentage of the actual cost, which is paid in the first place to the County Council. The latter body distributes the grants to those local authorities in the County who are entitled to claim the right to maintain the roads

within their respective areas, and to any others who maintain under agreement with the County.

The County Council is entitled to pay—from the County Rate—a further proportion of the cost and also towards the cost of work not ranking for government grant, such as scavenging, lighting of refuges, tree planting, etc. In some cases it is the policy of the County Council (e.g. Middlesex) to bear the whole cost of such services plus a percentage to cover overheads.

The usual procedure is for the urban authorities within the County having 'claimed' roads (urban councils of over 20,000 population) early in the autumn of each year, to submit to the County Engineer detailed estimates of expenditure for the ensuing financial year. The roads concerned are inspected by the County Engineer and the estimates discussed with the engineer to the local authority. After any amendment considered necessary, those portions of the estimates which relate to expenditure ranking for government grant are submitted for approval to the Ministry of Transport Divisional Engineer. In some cases the sums available for road maintenance are rationed and the estimates must be kept within the rationed figure.

Estimates in respect of roads directly maintained by the County are prepared by the respective Divisional Surveyors and submitted to the County Surveyor before submission to the Divisional Engineer of the Ministry of Transport. All estimates must be approved by the County Council before being sent to the Ministry.

The unclassified country roads in rural districts are often 'delegated' for maintenance purposes to the Rural District Councils, but generally the Highway Surveyors to those Councils are paid by and under the control of the County Council.

Upon final approval of the estimates the urban authorities are informed of the respective amounts allocated to them and details of the whole of the estimates for each Division are supplied to the Divisional Surveyor. It is usual for the Urban Councils to submit quarterly statements of expenditure, and subject to satisfactory reports by the Divisional Surveyor, to receive from the County payments on account. On submission of the annual account and a like report, a payment of 90 per cent. or 95 per cent. of the expenditure or of the estimate—whichever is the smaller—is made by the County, and the balance after audit. The County Surveyor is generally responsible for the audit, but in some cases this is conducted by a representative of the County Surveyor and one from the County Treasurer. Returns in respect of claims upon the Ministry of Transport for grants in connection with classified roads are based upon the accounts and particulars supplied by the Urban Councils, and the reports of the Divisional

Surveyors and actual expenditure by the County on roads directly maintained.

Divisional Surveyors, in most cases, are provided with an office within their Division, with clerks and other assistance as may be necessary.

The practice in reference to the provision of transport for the use of the divisional staff varies. In some counties vehicles are provided and maintained by the Council ; in others they are provided and maintained by the respective members of the staff. In some cases the Council requires Divisional and Assistant Divisional Surveyors to provide and run their own cars, for the use of which they are paid upon a mileage basis, whereas the Council provides foremen and others with motor-cycles and box sidecars for the conveyance of stores, tools, etc., and pays all running costs.

In some counties Divisional Surveyors are responsible for the supervision of general repairs and small improvement works only, large improvement works being controlled from head office, whilst in others Divisional Surveyors take control of all works within their respective divisions. It is usual in any event for all surveys to be made, plans, specifications, etc., prepared, and tenders invited by head office for all road and bridge works of importance. These works are supervised from head office, a clerk of works or resident engineer being engaged upon contract works of any extent. Measuring up, settlement of contractor's accounts, and certifying payments are also done by head office staff. Divisional Surveyors examine bridges at regular intervals and report to head office.

In most counties all roads are divided into lengths upon each of which is employed a 'beatman' or 'lengthman,' who is responsible for keeping his length in good condition so far as this can be done by patching and attention to drainage, margins, etc. These men also act as the 'eyes' of the Divisional Surveyors by reporting damage, encroachment and other matters concerning the highway. In some cases the Council allocates an annual sum which is distributed as a bonus to lengthmen who maintain their sections in the most satisfactory condition.

Reconstruction, resurfacing or extensive patching, as well as surface dressing and other work requiring the employment of a number of men, transport or plant, is executed by a gang under the direction of the Divisional Surveyor.

Divisional Surveyors engage and discharge all temporary labour but usually submit to the County Surveyor the names of men recommended for permanent positions. They have the power to dismiss men on the permanent establishment subject to a right of appeal by the man to the County Surveyor.

The practice of most counties is to enter into annual contracts for as many as practicable of the materials required, as well as for haulage, hire of rollers, etc. For information on this, including specifications, etc., see ⁴¹³.

In some counties these contracts are available for other authorities in connection with work over which the County exercises control, the County retaining the right to approve of specifications, sources of supply and conditions of contract.

Divisional Surveyors requisition supplies from head office, where the requisitions are checked with the approved estimates before orders are issued. It is a growing practice of highway authorities to own and operate such vehicles, rollers, and other plant as they can employ continuously and hire as may be necessary to supply irregular requirements. The execution of as much work as practicable by administration is also growing in favour. Divisional Surveyors are responsible for verification of quality and quantity of supplies.

Contractors' accounts are delivered to head office and are then sent to the Divisional Surveyors for certification and allocation. At head office all payments are entered under the various headings in the estimates. In many cases charts are prepared showing month by month the expenditure and commitments under various heads as compared with the estimates ⁴¹³. These form a valuable guide for the County Surveyor and enable him to regulate progress and expenditure. Diagrammatic records are also kept to enable comparisons to be made of cost, length of life, etc., of various materials and methods of treatment and construction.

A weekly time-sheet is filled in by each workman and foreman giving particulars of time worked each day and nature and situation of work. These sheets are signed by the man, and countersigned by the foreman and delivered to the Divisional Surveyor. After being checked and certified the sheets are sent to head office where the rates of pay and amounts are verified.

The payment of wages to a large number of men scattered over a wide area presents serious difficulties. The system followed varies. In some counties a cheque for the net amount of his wages is posted to each man. This involves considerable labour and expense and is not in favour with some of the men, who generally have to cash the cheque with a local tradesman. The main objection appears to be that this ties them to some extent to the tradesman. Generally cheques are sent fortnightly, the Council holding three or four days' pay in hand. In the larger counties, however, this system, on the whole, is probably the most convenient, so far as concerns men employed permanently or for a considerable time. It could not, of

course, be applied to casual men engaged for short periods, and arrangements must be made for funds to be available to Divisional Surveyors to enable them to pay men of this class.

The system in operation in some counties—generally those with the smaller or more compact areas—is to send cheques for the total amount of wages shown to be due by the certified time sheets, to the Divisional Surveyors, who cash the cheques, make up and place in a bag the money due to each man and send pay clerks round the Division by car, paying the men and securing their signatures. It is essential that a foreman or other responsible man capable of identifying every man as he is paid should be present at the time of paying. Whatever system of paying is adopted it is usual for health and unemployment cards to be deposited at head office.

Costing forms one of the most valuable sections of head office work, particularly where much work is executed by administration and the County operates its own production plant, quarries, etc.

Whilst it is important that costing should be done to an extent which will enable a high standard of efficiency to be maintained, it is easy to waste both time and money in the keeping of records and ascertaining of costs in excess of what is of any real value.

This subject may be divided into two parts, viz. (a) costing periodically for comparison of expenditure with estimate and (b) unit costing.

One of the Authors has made it a practice to measure up and value upon the basis of the estimate rates, works carried out by administration, at monthly intervals, as is done for contractors' monthly certificates. The figure so ascertained and the actual cost are plotted on a chart and a note made of the cause of any excess expenditure or saving. The position of each job can be seen at a glance and followed from month to month. In this connection it is convenient to give every section of work or job a Vote or Works number, to which all relative expenditure is allocated.

Unit costing is particularly useful where similar work is being carried out by different sections of the staff, but to enable reliable comparisons to be made it is essential that any variations in conditions should be noted and assessed. For instance, cost of raw material, length of haul, and other conditions may differ substantially in different parts of a County or even of a Division.

Unit costing is also useful for comparing different materials and processes, and for controlling output of plant, and work done by hired transport, etc. General unit costs such as average annual cost per mile of highway maintenance, or per 1,000 yards surface of road surface scavenged, are utterly useless and usually misleading.

It is now generally agreed that costing loses much of its value unless it is done by the Surveyor.

A selection of typical forms used in connection with county highway work is given in Appendix VII accompanied by explanatory notes, so far as these are necessary. Many others may be found ⁴¹³.

Certain other records are desirable in addition to those required for costing purposes. In some counties, the Divisional Surveyors or other responsible assistants are required to submit for the County Surveyor's approval, before commencing works, a programme in the form of a chart of operations, with the estimated number of men, etc., to be employed; time required for completion of each stage, and expenditure for each stage under different headings.

Corresponding details in relation to the work as it proceeds are plotted upon the chart, so that those in charge of the work are kept informed of the position and full control can be exercised by the County Surveyor.

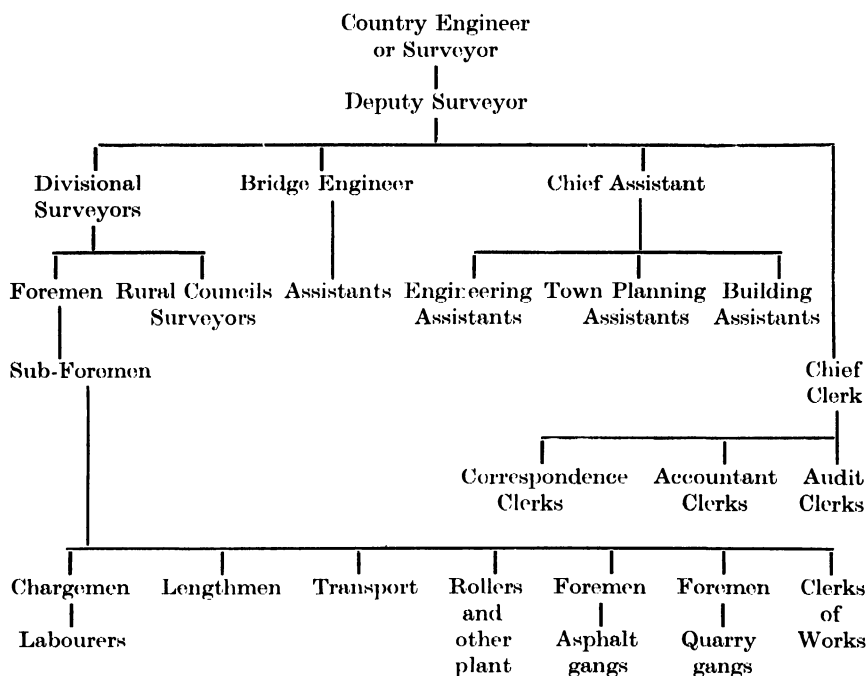
One important section of the work of a Highways Department is the control and reinstatement of road openings by statutory and other bodies. Notices and applications in reference to openings may be sent direct to head office or divisional office, but in either case reinstatement is carried out or supervised by the Divisional Surveyor who certifies the cost, the account for which is rendered either by head office or by the Treasurer. The practice as to trench reinstatement varies in different towns and counties.

In some cases reinstatement is carried out by the highway authority at the expense of the body or person responsible for the opening, the charges being based either upon an agreed schedule or upon actual cost plus a percentage to cover supervision and other overheads. In others the highway authority merely supervises the reinstatement. Where the highway authority undertakes the work they usually do so, in the case of statutory bodies, upon receipt of a written order and render the account on completion. When this class of work is undertaken for individuals or non-statutory bodies they are required to deposit the amount of the estimated cost before the work is commenced.

Organization of a County Highway Department.

The system of organization indicated on page 329 is typical of that adopted in many counties with such variations as are required to meet local conditions.

The number of Divisional Surveyors, Foremen, etc., varies with the size of the county.



Contracting—Lowest Tender.

Sec. 174 of the Public Health Act 1875 required local authorities before placing any contract of an amount of £100 or upwards, to invite tenders by public advertisement, and authorities were under pressure to accept the lowest tender.

This Section was repealed by the Public Health Act 1936, and Sec. 266 of that Act makes it unlawful for an authority to make contracts other than in accordance with their standing orders, which orders must provide that tenders shall be invited by public notice. Model Standing Orders drafted by the Ministry of Health contain a provision that a tender, other than the lowest (or highest, if payment is to be made to the authority), may not be accepted until the authority has considered a report thereon from their appropriate officer.

This reference to an experienced local government officer is a proper and reasonable requirement. There was a time when the placing of orders by local authorities was not infrequently influenced by favouritism, sometimes of a corrupt character, which the requirements of the 1875 Acts did much to prevent.

The acceptance of the lowest tender, however, is not always in the public interest, and at times to do so is to ask for trouble. In respect

of much of the work of a local authority quality is more important than cost, e.g. a road foundation or a deep-level sewer.

It is essential, therefore, that specifications should be as clear, and definite, as possible. It is desirable, also, that tenders for work of any importance should be based upon carefully prepared bills-of-quantities, priced by persons tendering, and submitted with their tenders. The latter should be checked for mistakes, and, where a tender is suspiciously low, for items obviously undercharged, and the contractor should be asked to confirm his tender. 'It is the practice of some Councils to intimate to a contractor, who desires to withdraw a tender, that if he does so, he will be disqualified from tendering in future. This may be prejudicial to the interests of the Council, where the withdrawal is caused by a genuine mistake. In some cases it may be desirable to make inquiries as to the competency of a lesser-known contractor.

The position is still unsatisfactory and still being discussed⁶¹⁶. In any case, it is essential, when public money is being expended, that contracts should be placed without fear or favour; that there should be no suspicion of unfair or corrupt dealing; and that honest value should be given.

The position is obviously surrounded with difficulties. There is no doubt, however, that both the public and the capable and honest contractor benefit by the issue of definite, precise and clear specifications and drawings; the scientific examination of ingredients and mixtures; and careful enlightened and reasonable supervision.

There is much to be said in favour of a prolonged maintenance provision in connection with some classes of highway work, under some conditions, as this type of contract may pay both the Council and the contractor.

The contractor having the responsibility for repairs is likely to take great care in executing the work to reduce to a minimum his future liability, and the ultimate cost to the Council is likely to be no greater, and possibly less. This is particularly the case where normal repairs are not sufficient to justify the Council in maintaining a staff and plant, and the contractor has good local facilities for executing repairs.

Experienced contractors are now quoting very favourable terms for prolonged periods of maintenance. It is recognized, for instance, that where an asphalt road, to a suitable specification for local traffic requirements is constructed satisfactorily, maintenance charges should be practically nil for the first 3 or 4 years, and it is not difficult to estimate, within reasonable limits, the cost of repairs over a longer period. The first 12 months is usually the most critical time. The risk from serious defects is found to be very small when it is spread over a large number of roads.

III

LAW OF HIGHWAYS

The Law of Highways is so wide a subject that it cannot be dealt with fully in a book of this kind. Reference has been made to some aspects of the question in other chapters (e.g. Private Street Works and Mains and Cables in Streets), and it is intended here to refer briefly to some of the more important matters dealt with by enactments relative to highways.

The following is a list of the principal Acts, but provisions referring to highways are found in numerous other Acts, old and new. The time is long overdue for a consolidation of the law relating to highways ²⁹⁵.

Principal Acts.

Highways Act 1835. (H.A. 1835.)

Towns Improvement Clauses Act 1847. (T.I.C.A. 1847.)

Public Health Act 1875. (P.H.A. 1875, largely repealed and superseded by P.H.A. 1936.)

Highways and Locomotive (Amendment Act) 1878. (H.L.A. 1878.)

Public Health (Buildings in Streets Act) 1888. (P.H.A. 1888.)

Public Health Acts Amendment Acts 1890, 1907, and 1925. (P.H.A. 1890, and P.H.A. 1907.)

Highways and Bridges Act 1891. (H.B.A. 1891.)

Private Street Works Act 1892. (P.S.W.A. 1892.)

Local Government Act 1894. (L.G.A. 1894.)

Development and Road Improvement Funds Act 1909. (D. and R.I.A. 1909.)

Ministry of Transport Act 1919. (M. of T.A. 1919.)

Acquisition of Land (Assessment of Compensation) Act 1919. (A. of L.A. 1919.)

Roads Act 1920. (R.A. 1920.)

Roads Improvement Act 1925. (R.I.A. 1925.)

Local Government Act 1929. (L.G.A. 1929, 1933.)

Bridges Act 1929. (B.A. 1929.)

Road Traffic Act 1930. (R.T.A. 1930); 1934, 1936 (Driving Licences).

The General Paving (Metropolis) Act 1817—Michael Angelo Taylor's Act (G.P.A. 1817.)

Metropolis Local Management Acts 1855, 1862 and 1882. (M.M.A. 1855; M.M.A. 1862; and M.M.A. 1882.)

Road and Rail Traffic Act 1933.

Trunk Roads Act 1936.

Road Traffic Act 1937, amending Road and Rail Traffic Act (Public Service Vehicles).

The following are Books dealing with Highway Law :

Pratt's *Law of Highways*.

Glen's *Law of Public Health and Local Government*.

Lumley's *Public Health Acts*.

A summary of the law relating to highways by H. Fawcett Payne.

Journal of the Institution of Municipal and County Engineers, Vol. LVIII.

Handbook of Municipal Engineering Law, J. R. Oxenham, published by the Institution of Municipal and County Engineers, 1932.

The Law relating to Highways, H. H. Copnall, published by Knight. Macmorran's *Private Street Works*.

Annotated Model Byelaws, T. P. Frank, published by Knight.

Highway and Road Traffic Law. Roadmaker's Library. R. P. Mahaffy.

New Roads and Streets, and Street Improvements.

Acquisition of land. Urban Authority power to acquire land for new streets and improvements. P.H.A. 1875, SS. 154, 175, 176 ; P.H.A. 1907, S. 95 ; P.H.A. 1925, S. 83. Power given to County Councils. L.G.A. 1929, SS. 30 and 31. P.H.A. 1936, Part VII.

Power to construct new roads and to contribute towards cost. Urban Authority power to contribute towards cost of new road. P.H.A. 1875, S. 146 ; P.H.A. 1925, S. 81 ; County Councils L.G.A. 1929 SS. 30, 31 ; Ministry of Transport may purchase land not exceeding 220 yds. from centre of new road. Ministry of Transport may authorize local authority to construct and maintain new roads and may contribute towards cost. D. & R.I.A. 1909, S. 8 ; M. of T.A. 1919, S. 1.

By-laws. Urban Authority power to make by-laws in reference to new streets. P.H.A. 1875, S. 157 ; Rural District Councils. L.G.A. 1894, S. 25 ; L.G.A. 1929, S. 30.

Private Street Works.

Urban Authority power to require private street to be made up by abutting owners or in default to execute necessary works at cost of owners. P.H.A., S. 150. Power to make up private street and recover cost from frontagers, subject to right of appeal by latter. P.T.W.A. 1892 (adoptive). Authority power to vary width carriageway and footway in private street. P.H.A. 1925, S. 35 (adoptive).

Dedication and Vesting of Streets in Highway Authority. Urban

Authorities. P.H.A. 1875, SS. 144 ; 149 and 152 ; P.H.A. 1890, S. 41 (adoptive), P.H.A. 1925, S. 82, P.S.W.A. 1892, S. 19 and S. 20 (adoptive). County Councils, L.G.A. 1929, S.30.

Building and Improvement Lines.

A building may not be brought forward beyond the front main wall of the building on either side. P.H.A. 1888. Building lines may be prescribed. R.I.A. 1925, S. 5. Regulation of line of buildings in street. P.H.A. 1875, SS. 154 and 155. Improvement lines may be prescribed. P.H.A. 1925, SS. 33 and 34 ; R.I.A. 1925, SS. 4 and 5.

Power of local authority to adopt or repair. P.H.A. 1875, SS. 146 and 147. H.L.A. 1878, S. 21.

Bridges.

County Authority may contribute towards cost. L.G.A. 1888, SS. 3 and 11 ; H.C.A. 1878, S. 22. County Council take over main road bridges. L.G.A. 1929, S. 29. Bridge Authority power to erect notices restricting load on weak bridges. R.T.A. 1930. S. 24 and S. 48. Improvement and Strengthening of Bridges. B.A. 1740 ; H.B. 1891, S. 3 ; M. of T.A. 1919, SS.1, 11, and 17. Repair of Bridges. L.G.A. 1888, S. 3. Ministry of Transport Grants. M. of T.A. 1919, S. 17. Private Bridges over Streets. P.H.A. 1925, S.S 27 and 28. Breaking open of Bridges. P.H.A. 1936, S. 279.

Repair of Streets.

Local Authority to repair. P.H.A. 1875, SS. 144, 149 and 216 ; L.G.A. 1929, S. 30 ; L.G.A. 1888, S. 11. Precautions during repair. P.H.A. 1875, S. 160. Local Authority may execute urgent repairs in Private Street. P.H.A. 1907, S. 19. Local Authority not liable for non-repair. P.H.A. 1875, SS. 144 and 149.

Easements.

Power of undertakers to open streets. Telegraph Act 1863, SS. 6, 9, 10, 12, 13 and 17. Waterworks Clauses Act 1847, SS. 28, 30, 31, 32 and 34. Gas Clauses Consolidation Act 1847, SS. 6, 8, 9, 10 and 11. Electric Light Act 1882, S. 7. Electric Lighting Clauses Act 1899, SS. 11, 12, 13 and 14.

Obstructions and Encroachments.

Power to prevent encroachments. P.H.A. 1875, SS. 144, 160 and 171 ; L.G.A. 1888, S.11 ; L.G.A. 1929, SS. 29, 30 and 31 ; P.H.A. 1925, SS. 24 and 4 ; R.T.A. 1930, SS. 51 and 56 ; P.H.A. 1907, S. 29.

Street Refuges, Light Signals, etc.

Power to erect. R.T.A. 1930, SS. 48, 55 and 57 ; P.H.A. 1925, SS. 13, 14 and 15 ; P.H.A. 1890, SS. 39 and 40.

Parking Places.

Local Authority may provide. P.H.A. 1925, S. 68. Parking in streets. R.T.A., S. 90.

Lighting of Streets.

Power to provide public lighting. P.H.A. 1875, S. 161 ; L.G.A. 1888, S. 11.

Naming of Streets.

P.H.A. 1875, S. 160 ; P.H.A. 1925, SS. 17, 18 and 19 ; P.H.A. 1907, S. 21.

Stopping-up and Diversion of Highways.

H.A. 1835, SS. 84-92 inclusive ; H.A. 1864, S. 21 ; P.H.A. 1875, S. 144 ; L.G.A. 1888, S. 11 ; L.G.A. 1929, S. 30 ; Housing Act 1930, S. 13.

Temporary Closing of Highways.

P.H.A. 1875, SS. 144, 160, 171 ; L.G.A. 1888, S. 11 ; R.T.A., SS. 46 and 47.

Extraordinary Traffic.

R.T.A. 1930, S. 54 and Schedule 5 ; M. of T.A. 1919, S. 10.

PART XI

SCIENTIFIC

‘ ORGANIZED KNOWLEDGE ’

There are various definitions of ‘science,’ of which the best is ‘organized knowledge.’ Both words have equal weight, as knowledge is not science until the new facts ascertained by research have been marshalled into recognizable order.

Having done this, the next step is to make this new knowledge available to the world, and this problem has been fairly well solved in most divisions of science and technology, but not all.

Like the great sciences, the great industries, such as those of engineering, rubber, and building, have developed organizations for the collection and dissemination of information concerning the scientific, technical, industrial, and financial progress of their several interests. In the road industry there was nothing systematic. Certain technical journals, in addition to the Institution of Civil Engineers and the Institute of Petroleum, gave abstracts so far as their space would allow, but there was no full-scale attempt to study the 100-odd road journals of the world, and to make known everywhere the best that is in them. To-day the industry is well catered for, mainly through the Roads and Building materials group of the Society of Chemical Industry, the road section of the Institute of Civil Engineers, and *Road Abstracts*.

It should be remembered that the valuable publications of the Swedish Road Institute contain summaries in English. This is also done in the Dutch *Chemisch Weekblad*.

EDUCATION AND SCIENTIFIC GUIDANCE

For a long time it was clear to many of those interested in this subject that chemistry and physics must be allowed to take their place, shoulder to shoulder with engineering, in attacking the problems associated with road improvement in the widest sense. This did not mean that engineering was a failure and must be supplanted, but it did imply that problems were changing in character and that these

younger sciences should contribute their share in the burden of progress. For this purpose, road research, at long last, was established on a wide and firm basis.

The formation of a Road Laboratory, comparable to those of which there are so many on the Continent and in America, was publicly discussed and approved ⁴ by all the interests in the industry and profession as far back as 1929 ; but oppressive activities led to the matter being dropped. There remained a feeling of simmering dissatisfaction at this position, as there was ample room for both governmental and industrial schemes of research and investigation to develop, as the requirements of the two were different and to a great extent complementary.

The experiment of the Ministry of Transport running a scientific laboratory by means of departmental machinery was watched with interest and a certain sympathetic apprehension. It was hard to see how the best scientific work could be done with a background of Treasury control, the possibility of uninformed questions in Parliament, of the publication of laboratory results possibly being determined by 'policy,' and the speed of action being of that deliberation usually associated with departmental activities.

The experiment was insufficiently successful and early in 1933 the laboratory was transferred to the control of the Department of Scientific and Industrial Research, a Department called into being soon after the first Great War to deal with the application of science to industry on a big scale. At the same time, the Ministry of Transport and the National Physical Laboratory took an intimate part in the work of the laboratory, which afterwards was concentrated in the Road Research Laboratory at Harmondsworth.

The complaint has been made that the results achieved by a research laboratory are 'too academic' for use in practical work. This is based on a misconception. When technical processes are investigated by a research chemist employing the most specialized methods available, basic principles are elucidated, independent of local conditions and requirements in a works or factory. This new knowledge can then be applied and adapted to manufacturing conditions, and it is the business of the Chemist of the Producer to use this new knowledge and to carry out this transformation. As a matter of fact, the Road Research Laboratory is deeply interested in the practical application of its more fundamental investigations.

For example : supposing the research chemist makes discoveries concerning the inter-molecular activities that control viscosity. It is not necessarily his business to carry it any further ; it is the duty of the works chemist attached to the various tarmacadam, asphalt, and road

emulsion producers to make practical use of the new knowledge, each in his own sphere of interests and each according to the details of his own material and manufacture.

Such scientific activities, obviously, relate to the manufacturing end of road making—to the properties of components and of their mixtures. There is also the other end, namely the buyer, who should be in the position to inform himself that the proportion and quality of the materials being laid are in accordance with the Contract.

There should also be ample means for analyses to be made on samples taken from the road before or after laying. The work must be done by those specializing in it; however admirable may be the normal work of the qualified analytical chemist, particular knowledge is required for road matters.

The technical *education* of the budding engineer and surveyor may begin in the University or Technical College or in the Highway Engineer's office. Information of courses of study has been obtained by the courtesy of the Professors concerned, and is summarized in the Table on p. 338.

Practical experience is obtained by the junior in a senior's office; and his qualifications are tested by examinations held by the Institution of Municipal and County Engineers ²⁹⁸, and the Institution of Highway Engineers ²⁹⁹. Details are easily obtained, and need not be treated further here.

During the War, the Road Research Laboratory at Harmondsworth gave short courses on road construction to Services personnel and to a few civilians also. These have now been developed into courses of instruction to highway engineers. Instruction in soil problems has been given for some years past at the Building Research Station at Garston.

Amongst these institutions, a very interesting foundation is the *Maybury Chair of Highway Engineering*.

On Feb. 5, 1925, the Master of the Worshipful Company of Paviers announced the imminent receipt of a Report of a special committee on a scheme to found a Chair of Highway Engineering. This was the result of several years of discussion between the Paviers' Company, the Ministry of Transport, and the London University Authorities; and, in recognition of his work for the roads of England, Sir Henry Maybury was pressed to consent to have his name associated with it.

It was originally intended that there should be a three years' course, leading to the degree of B.Sc. Highway Engineering. This proposal, however, was soon changed to a single-year course at the City and Guilds (Engineering) College, open to those students who had

Name of Institution.	Department Concerned.	Road Engineering : Remarks.
<i>Belfast :</i> Queen's University . . .	Civil Engineering	No special attention to roads.
<i>Birmingham :</i> The University, Edgbaston	„ „	Included.
<i>Bristol :</i> The University . . .	„ „	Included.
<i>Cork :</i> University College . . .	„ „	Road engineering 'emphasized' in Civil and Municipal Engineering Courses.
<i>Dublin :</i> University College . . .	„ „	Special course.
<i>Edinburgh :</i> The University . . .	Engineering	Part of final year's course in Civil Engineering
<i>Glasgow :</i> The University . . .	Civil Engineering	No special course.
Royal Technical College .	„ „	No special course.
<i>Leeds :</i> The University . . .	„ „	Part of Honours B.Sc. course.
<i>Liverpool :</i> The University . . .	„ „	Included.
<i>London :</i> University College . . .	Civil and Municipal	Part of final year's course.
Imperial College of Science and Technology . . .	Civil Engineering	Maybury Chair in abeyance: no course in road construction.
King's College	Civil and Mechanical Engineering	No special course.
City and Guild's College .	Civil Engineering	Not included.
Battersea Polytechnic .	Engineering	In civil engineering and surveying courses.
Northampton Polytechnic	Civil Engineering	Included.
<i>Manchester :</i> The University . . .	Engineering	No specialized instruction.
<i>Newcastle :</i> King's College	„	In final year. First university in this country to develop soils laboratory.
<i>Nottingham :</i> University College . . .	Civil Engineering	No special instruction.
<i>Sheffield :</i> The University . . .	„ „	Included.
<i>Southampton :</i> University College . . .	Engineering	No special course.
<i>Swansea :</i> University College . . .	„	Included.

already taken the Diploma of Civil Engineering or its equivalent, who wished to take the Diploma of the Imperial College (D.I.C.), for which a thesis on some research work may be presented.

The scheme was started for a trial period of five years and in November 1928, Major R. G. H. Clements, M.C., was appointed the first Professor, and the full course began in 1929. This consisted in tutorial work, laboratory experiments and research, and visits to works and quarries.

Whilst, generally, it was agreed that the course itself was excellent, and that it was most ably conducted by the Professor, some disappointment was expressed that the number of students taking advantage of it was comparatively small and that of these a large proportion was non-British. Whilst it was recognized that the nation might benefit indirectly by the training of road engineers from other countries, it was felt that as the funds were contributed, almost entirely, by local authorities and others keenly interested in the roads of this country, the primary object of the promoters of the scheme was not being given full regard.

The climax was reached when the University authorities announced that upon the retirement of Professor Clements, the Chair could continue only if a full-time professor must be appointed, and the subscribers provided a capital sum, the interest from which would cover the whole cost. As the sum involved far exceeded the available resources, it regretfully was decided that the Chair of Highway Engineering must be abandoned. After considering various proposals for utilizing the available funds for the advancement of highway engineering, it was agreed at a joint meeting in July 1946, to suspend activities for a period of two years, to allow time for the formulation of a new scheme.

INFORMATION

The sources of information of current British activities relating to road matters are adequate, and can be found in a series of *publications* (see Appendix II), but considerable demands on time and patience were made until, at long last, *Road Abstracts* made its appearance in 1934. This was compiled by the Department of Scientific and Industrial Research and the Ministry of Transport, and covered a world-wide field of information. These abstracts are supplied to any technical journal asking for them, and appear as a supplement to the journal of the Institute of Municipal Engineers and to the journal of the Society of Chemical Industry for the members of the Roads and Building Materials Group; but they can be purchased separately.

As one of the results of the International Road Congress in Washing-

ton, in 1930, the Permanent Association of Road Congresses, in Paris, published a valuable periodic *Bibliographic Index* of road information, which was issued only to members of the Association.

Technical *libraries* are supplied with books and foreign technical journals that are useful to the road maker. In London, there is the British Museum Library and also the Science Library at South Kensington, and the Patent Office Library, off Chancery Lane. The Road Research Laboratory at Harmondsworth has a complete collection of information in its library ; and its Reports and Bulletins are of the greatest scientific and technical value, and should be closely studied.

With regard to *filing* and *indexing* of information collected by the individual or the firm, the essential requirement is that any item shall be made available in the minimum of time. Facts can be recorded on cards ; letters, cuttings and pamphlets should be kept in filing cabinets, and indexed under *Subject*.

When such a collection of information is to be used only within the four walls of the collector, indexing is fairly simple and a system can be chosen that is suitable to personal and local requirements. The moment that contact has to be made with collections of data in foreign countries, detailed collation and union of matter becomes of the greatest difficulty owing to difference of language leading to different indexing headings. Confusion became so great that indexing founded on the alphabet has been abandoned and numerical systems have been substituted for it.

The central principle is the allocation of numbers to the main divisions of human knowledge, and subdivisions of these are given decimal figures. The first widespread system was the Dewey system of America, which has been extended and is being superseded by the more highly developed system of the International Bibliographical Institute, with its headquarters at Brussels (Parc du Cinquantenaire) ; its British section is at the Science Library, South Kensington.

INVESTIGATION AND RESEARCH

The condition of the roads of Great Britain was atrocious down to the beginning of the nineteenth century, the days of Macadam and Telford. When the advancing commercial progress rendered the construction of proper roads a supreme necessity, the professional road maker developed from being a man of any trade or none, and only incidentally and sometimes fraudulently a road maker, into an engineer of high capabilities. He planned his road, carried it across country and surfaced it to bear traffic. In devising the surfacing he

displayed a penetrating common sense founded on experience, the experience obtained by trial and error. This lasted until the advent of the motor-car, when the existing water-bound macadam and the later rough-and-ready tarmacadam mixtures failed to stand up to the new type of traffic. It became imperative for chemistry and physics to collaborate with engineering to catch up with the new demands. These sciences gained their entry into the road industry through the dust-laying liquids required during the transition period after the collapse of macadam, which then became a serious menace to the health, comfort, and amenity of the community, and threatened the progress of the new form of transport. They developed through the requirements of asphalt and of tar surfacings, though chemical work was being done on compressed asphalt for city streets long previous to this time. Finally, concrete became intensively studied in all its numerous and difficult problems. The response of the roads to modern requirements would have been impossible without organized research.

Most of the development work has been done, and has become established in various British Standard Specifications. But this has not discouraged a great deal of work being carried out, the results of which require the revision of the specifications from time to time.

The type of scientific, as apart from routine, work required is of two kinds: (a) *investigations* into current problems for immediate solution and use, and (b) *research* into the scientific principles underlying the phenomena on which the life of the road surface depends, as well as into those more fundamental matters that are of value to the industry and community as a whole.

This simple division corresponds with the resources of the laboratories of individual firms on the one hand, and educational institutions and Governmental organizations on the other. Thus, the two types of laboratories and the work that they can most suitably carry out are complementary to one another.

Official Laboratories

The *Road Research Laboratory*, which was known as the Ministry of Transport's Experimental Station until 1933, is situated at Harmondsworth (West Drayton), near the Ministry's experimental road, which is the only road reserved exclusively for the Laboratory's tests.

The preliminary buildings were completed in November 1929, at a cost of about £14,000; working order was reached in April 1930, and the full staff was engaged in August. A good description of the Laboratory at the beginning of its career has been published ³⁵³.

A very important development took place when the Department of Scientific and Industrial Research took over the Laboratory as from May 1933, and appointed a Road Research Board, whilst the Ministry remained intimately connected with the new organization. For the first time in our road history, the sciences of chemistry and physics and geology took their places as colleagues of engineering. One result has been the co-ordination of road research at Harmondsworth with the work of the Building Research Station at Garston.

Great developments have occurred, and the Laboratory's present position and activities have been summarized as follows : .

The Laboratory is primarily devoted to studying problems of general nature that arise in designing, building, and maintaining public highways. The main objectives of the work, which is undertaken in close co-operation with the Roads Department of the Ministry of (War) Transport, are to improve the road as a channel for traffic, to reduce the overall costs of construction and maintenance, and to promote safety and comfort in travel.

Advice on the conduct of investigations is given by the Road Research Board and by committees appointed to deal with specific subjects. Certain parts of the programme are undertaken co-operatively with trade associations which contribute financially to the cost of the work, and appoint representatives to joint advisory committees. The Road Research Board was reconstituted in 1946, the revised terms of reference being :

‘ To advise on the conduct of research on roads, to include road safety, and on cognate subjects ; to submit annually a programme of work with special reference to any new work it is proposed to undertake ; to submit an annual report.’

The Board is assisted by Committees on Soils, Pavings, the Use of Machinery in Road Construction, Roads, Vehicles, Road Users, and Statistics. Thus, the first three Committees are mainly concerned with materials and methods of construction, and the remainder mainly on road safety and traffic flow. The Committee on Road Users is a joint Committee of the Road Research Board and the Medical Research Council.

In addition, there are several Advisory Committees concerned with the conduct of work carried out co-operatively with trade associations. There are four such Committees, the Associations being The British Road Tar Association, The Cement and Concrete Association, The Asphalt Roads Association, and The Timber Development Association. The members of these Committees are nominated in approximately equal numbers by the Department and by the Association concerned.

Special investigations for which a fee is charged are undertaken on request in certain cases. The Laboratory is prepared to investigate any material or process or problem if considered to be of sufficient importance.

The resources of the Laboratory include a very important reference library ; and lectures and tuition courses for road engineers are being held on the suggestion of important professional bodies.

The Laboratories at Harmondsworth and at Garston have both issued a stream of valuable Reports and Memoranda, and many communications have appeared in the technical Press.

During the War, long-term researches at Harmondsworth were continued, and many investigations were made on the military requirements of special construction both of roads and of aerodrome runways. In addition, co-operative research has been carried out with the British Road Tar Association and the Asphalt Roads Association, and the Cement and Concrete Association, together with many other important if minor developments. (See also ⁵²⁶.) An outstanding Paper, summarizing the work of the Road Research Laboratory, is that of Dr. W. H. Glanville, the Director of Road Research ¹⁷².

The *National Physical Laboratory*, Teddington, for long undertook mechanical tests of samples of road-stone and bituminous road mixtures when accompanied with a requisition from the Ministry of Transport ; results were reported through the Ministry to the transmitter of the sample. In addition, geological and petrological examinations were carried out by the *Geological Survey*. All this work has for some time been carried out at Harmondsworth.

Experimental Roads

In the closest connection with the Road Research Laboratory are the various experimental roads. Strictly, only the Harmondsworth By-pass is completely under the control of the Laboratory ; but the Colnbrook and Kingstone By-passes, the Liverpool-Salford (East Lancashire), the Bath-Bristol, and the North Circular roads are used for tests connected with the Laboratory's investigations, amongst many others.

In addition, there are many individual localities throughout the country where particular trials are made for the benefit of problems of general importance which have been brought forward by the local authority ; and to this the attitude of the Ministry is always sympathetic. The local authority is well advised to communicate with the Road Research Board before embarking on experiments, which may only repeat work that has been done already, or the value of which may be greatly increased by knowledge already available.

In some cases the local engineer has a suitable road on which he allows trials to be laid at the expense of the experimenter. One of the Authors for some years reserved for this purpose a length of road carrying heavy concentrated traffic, divided into short sections of material on trial, from which valuable information was obtained.

Local Authorities' Laboratories

The testing of supplies received by a Local Authority is necessary, not only for the protection of the traveller and the ratepayer from discomfort, delay, and waste, resulting from the use of inferior material, but also from honest mistakes. For instance, the grading of mineral aggregate may be erratic ; too hard a bitumen may be sent ; and non-compliance with a specification may occur.

At the moment of writing, the only Local Authorities which have been identified as having their own laboratories are the counties of Hampshire ³⁸², Surrey, and Lanarkshire, and the Woolwich Borough Council, together with good intentions of the West Riding County Council. Whether this is due to lack of understanding of what science can do or to a disinclination to risk raising the rates, the deficiency is to be deplored.

The recommendations given under *Works Laboratories* have much that can be used by those Local Authorities which wish to safeguard themselves (see also ³⁵²), but the following notes received from Hampshire (Brig. A. C. Hughes) may be additionally useful.

A *County Roads Laboratory* (Fig. XI.1) should be prepared to carry out the following duties :

- (1) The consideration, interpretation, and periodic revision of specifications.
- (2) The technical direction of the manufacturing of materials used in the construction and maintenance of road works.
- (3) The routine testing of material and mixtures used for the roads.
- (4) The selection and testing of mineral aggregates.
- (5) The scientific control of concrete mixes.
- (6) Soil testing.

According to local resources, large-scale testing, such as mechanical tests associated with cement and concrete, may have to be done by firms specializing in such work.

The Laboratory may consist of :

- (a) *Administration Offices*.
- (b) *Aggregate Grading Room*, for the testing of grading and shape of the material. Standard apparatus is employed, with balances :

Semi-automatic : range, 0-5 kg. accurate to 1 gr.

Spring: „ 0-15 lb. „ „ $\frac{1}{2}$ lb.

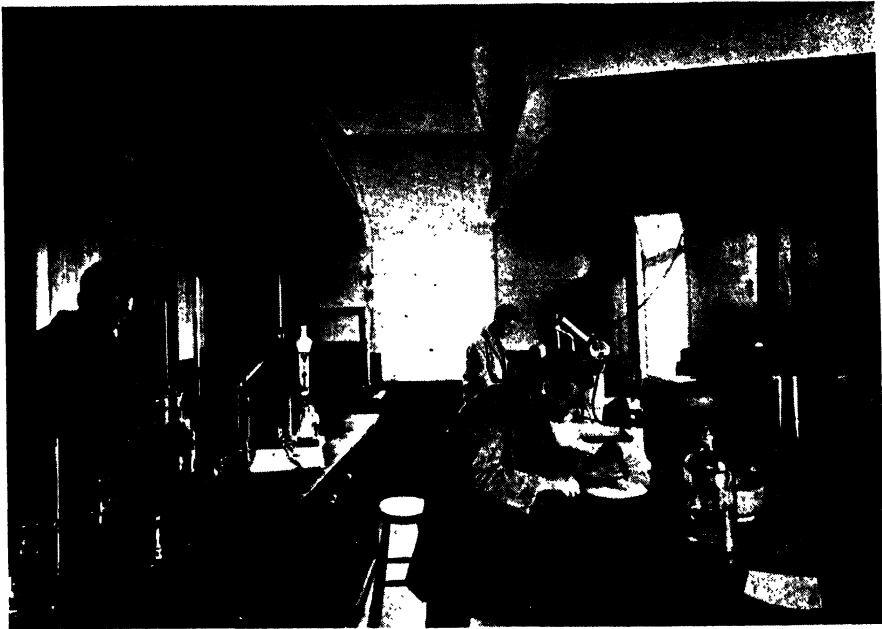
Beam : „ 0-1 kg. „ „ 10 mm.

1 sample of every 50 tons is usually sufficient.

(c) *Bituminous Mixtures Analysis Room.* In addition to the usual apparatus, there may be one or more hot extractors, a muffle furnace, and balances :

0-3 kg. accurate to 0.1 gr.

0-1 kg. „ „ 10 mm.



By the courtesy of Brig. A. C. Hughes (Hampshire).

FIG. XI.1.—County Surveyor's Laboratory.

Continuous routine control can be kept by means of a rapid method of analysis, such as that of Green and Cox.

The risk of fire requires continuous watchfulness.

1 sample for every 50 tons is usually sufficient.

(d) *Chemical Laboratory* (Fig. XI.1), for the testing of lubricating oils, bitumen, asphalt, road tar, and emulsions.

(e) *Wet Concrete Room.* The balance used may be 0-5 kg., accurate to 1 gr. The following proportions for test are recommended :

High strength concrete : aggregate/cement ratio, 6 : 1 by wt. (max.)

Medium „ „ „ „ „ 8 : 1 „ „ „

Low „ „ „ „ „ 12 : 1 „ „ „

(f) *Soil Testing Laboratory* is responsible for soil surveys, classification and compaction tests, preparation and test of soil mixtures. So far, no comprehensive standardization has been done, but some tests follow the methods of the Institute of Petroleum.

(g) *Balance Room.* Care must be taken to minimize vibration.

(h) *Store.* Solvents should be kept in a separate building. Representative portions of tested samples should be kept for 2 months.

(i) *Workshop,* for general and emergency requirements.

(j) *Staff.* Laboratory Manager, 2 Assistants (of at least Inter. B.Sc. standard), 1 Assistant (Matric. standard), 2 Laboratory Stewards.

Mobile Laboratories

A remarkable series of mobile laboratories have been developed by the Road Research Laboratory, primarily for its own purposes, but information about their production is easily available to those engineers who wish to have their own.

The laboratory for the testing of *bituminous mixtures* is fitted up in a body, 17 ft. long, 7 ft. 6 in. wide, and 6 ft. 6 in. internal height, and mounted on a 6-ton 4-wheeled trailer chassis. It is equipped for the standard tests of viscosity, penetration, and softening point, the grading of aggregate and fillers, and for the analysis of asphalt and tarmacadam. An analytical balance and a semi-automatic 7-kilo balance are included.

Three cylinders of Calor compressed gas are normally carried; electricity can be taken in from local supplies or be generated from a petrol-driven dynamo, which is driven on a trestle outside the laboratory so as to avoid vibration. There is also an emergency 12-v. 180-amp.-hr. accumulator. Water is carried in a 30-gal tank; one sink outlet runs to waste, and another to a storage tank from which the water can be pumped back to the supply tank. There is a fume cupboard with a small extractor fan; and two sleeping bunks, of which the upper can be reversed for use as an extra bench or as a back-rest when the lower is used as a seat.

For *concrete*, a very similar trailer laboratory has been devised, differing only in details of equipment. This includes a hand-operated 100-ton hydraulic compression testing machine, a standard motor cube vibrator, an electric sieve shaker, 7-kg. and 1-kg. semi-automatic balances, and the usual cement and concrete testing apparatus.

Three types of mobile laboratories have been developed for *soil analysis*. Type 1 is a standard R.A.F. caravan with sleeping accommodation for small jobs; Type 2 is a trailer for work on a larger scale and is comparable with the bitumen and concrete laboratories, and

Type 3 is a specially built body on a 3-ton lorry, equipped to carry out almost any test.

Experience gained by the Road Research Laboratory has enabled the Limmer & Trinidad Lake Asphalt Co., Ltd., to design a mobile laboratory for its special requirements, which is mounted on a 5-ton trailer chassis.

Works Laboratories

Design and Equipment.

The work required to be done by these laboratories includes routine checking of the quality of the raw materials and road mixtures ; examining of failures in so far as these are due to the materials or process employed ; improvements in production methods ; testing of proposed new materials and their application, of new methods of examination and analysis, and new manufacturing procedure ; periodic collation of results and preparation of Reports, statistics, and laboratory costs.

The continuous checking of the output of a plant—the percentage of binder, moisture, aggregate grading—enables faults and inefficiencies of the plant to be discovered ³³⁴, in addition to those of human origin.

The laboratory should work in close contact, collaboration, and confidence with Head Office. Everything possible should be done to make the operating side realize that the laboratory is not a watchdog ever ready to make trouble, but an organization to assist in the avoidance of trouble and the reduction of costs for the enhancement of the welfare of the firm.

Everything possible should also be done to minimize the isolation that is imposed on the laboratory through its highly specialized operations being carried out in a highly specialized building, usually apart from Head Office and the job. This could be done through short instructional courses to the junior operative staff ; by occasional visits from Head Office ; by frequent consultation between Head Office, the works, and the Laboratory ; by the attendance of the Laboratory Director at the periodic consultations of the heads of Head Office staff ; and by the Laboratory being kept continuously informed of the firm's activities.

The Building.

It is not often that there is an opportunity to build and equip a road laboratory from its foundation to its last tap. When this is contemplated, a book such as Munby's ¹ should be carefully studied, so that thoughts and ideas may be put in order before discussion

begins with an experienced architect. (See also ³⁰ for much useful matter.)

In these days of steel and glass and concrete there is much that should be remembered about brick buildings for laboratories.

Too much steel and glass puts the workers overmuch at the mercy of the outside climate and weather. In the winter there is little structural protection from the cold, and the worker may be chilled in front and cooked behind ; in the summer the laboratory approximates to a conservatory. Too great window area renders difficult the preservation of a constant temperature, for even if draughts are prevented, radiation is active. A brick building transmits temperature changes much more slowly, and smaller but sufficient window area is easier to control.

More often, a part of an existing building—not always the most suitable—is allocated to the scientific staff, with a strong hint about economy in expenditure ; and the best has to be made of it. In any case, the following notes and comments may be taken as covering general as well as bituminous work.

I. General Arrangement and Equipment.

1. The **Director's Office**, and typists' room. No special equipment is required beyond a very efficient Subject filing system. Correspondence can usefully be divided into two parts—routine, which is filed as usual, and that which contains useful information and is best included in the Subject files. Files should be kept with the utmost care, the ideal to be aimed at being to be able to answer a question from them whilst Head Office is on the 'phone, as well as to preserve for ready reference records of all information obtainable which may be of subsequent value.

2. The '**Rough**' **Laboratory**. Here all the dirty operations take place : breaking of samples preparatory to examination ; preparing of trial mixtures, with filler escaping into the air ; and the like.

3. The **Chemical Laboratory**. Here chemical operations are carried out which would be upset by any but cleanly conditions. The physical tests—viscosity, penetration, and the rest—can also be made here, if the atmosphere contains no fumes that will damage the apparatus.

4. The **Distillation Room**. When inflammable solvents are to be recovered, it is wise to do this in a separate room where all chance of ignition is rigidly excluded. Smoking must be absolutely forbidden, and electric switches must be placed outside ; ventilation fans must be of the induction type, or otherwise specially suited to a possibly inflammable atmosphere. The quantity of solvent used in asphalt

analysis may be considerable, so that means should be installed to recover this in bulk. The use of trichlorethylene in place of carbon disulphide as a routine solvent renders a special Distillation Room less important.

5. **The Balance Room.** Ordinary rough weighings can be carried out anywhere, but the condition of the balances must be carefully watched. When an accurate balance, that is one that is accurate to 0.1 mg. with 200 g. on each scale pan, is employed, it is essential that it should be housed in a room of clean, non-corrosive atmosphere of equable temperature, and carefully preserved from vibration and deviation from the absolute level. When a balance is illuminated, care must be taken against irregular heating.

6. **Photographic Dark Room.** Ventilation without ingress of dust is particularly important when so much fine material may normally be flying about.

7. **Apparatus.** The quantity of mineral matter of relatively large size which is examined in a road laboratory, tends to encourage the use of enamelled iron, stainless steel, and of aluminium vessels in place of glass; but when the latter is employed, the resistance type is preferable. Aluminium vessels must be kept out of contact with mercury.

Whenever possible, metal parts of apparatus should be chromium-plated in order to minimize the labour of cleaning. Stainless steel is also a desirable material.

The standardization of methods of tests need not discourage or deter the use of any other tests more suited to the requirements of any particular laboratory, or the employment of home-made devices in place of the relatively high-priced standard apparatus. At the same time, it is essential to follow standard methods exactly whenever there is the least likelihood of comparisons being made with results obtained in other laboratories, or in cases of disputes.

When synchronized clocks are available in a new laboratory, or are installed in the firm's main building near by and the circuit is available to the laboratory, it is valuable to have a ticker for use when determining penetrations, etc., to replace stop-watches and metronomes which may not be so accurate, and require occasional standardizing. When this is not possible, there is available a varied choice of time measuring or indicating instruments.

In routine work a pocket lens of about 12 magnification is valuable for examining sand grains, but better still is the special form of magnifier that indicates the size of grain at the same time. A microscope becomes essential for close examination of grains of sand and filler, and for work on rock sections and colloid phenomena.

A photographic camera of the reflex type is the best for recording details of road construction, traffic, and the like. Photographing against the direction of the light is often the only way to get details of a dark and almost uniform surface. In the laboratory a half-plate camera is to be preferred. When recording objects under the microscope an eyepiece camera is inevitable.

Care must be taken in the storage of standard and sub-standard instruments—thermometers, sieves, and the rest—that they may be kept clean and free from damage. A locked cupboard in the Director's office is probably the best place.

8. **Stores and Museum.** The storage of samples for a prescribed time, and the preservation of those of intrinsic interest, must be provided for; and considerable shelving space is required even when sorting and discarding is done at frequent intervals. The ideal is that all samples should be kept for reference in case any subsequent behaviour of the road should call for their examination; but in practice, samples may usually be got rid of after twelve months, except those of special interest.

Storage is much facilitated by the use of containers of definite and uniform size (or sizes). Care must be taken that descriptive labels do not become detached; gummed labels on tins frequently drop off.

9. **Library.** Usually this will not be large, but it must be provided for. The latest text-books, and catalogues, and current journals relating to the main subject and allied sciences, are essential. As a rule, they will not overflow one or two book-cases in the Director's office, unless a number of foreign journals are also taken and kept. Even then this is not likely if the valuable matter be removed from these and filed, and the bulk of the journal thrown away. A Press Cutting Agency may be very useful.

10. **Workshop.** When anything but simple routine work is carried out, this most valuable adjunct will save much time and expense.

II. Walls, Ceiling, and Floor.

1. The internal **Walls**, for the sake of cheapness, may be of discoloured plaster, or even brick whitewashed, for the sake of light and of minimizing the spread of brick dust, though the irregularities hold the dirt. Green walls are restful for the eyes. At intervals battens of wood should be fixed, vertical for carrying shelving, and horizontal for the fixing of apparatus, etc. Asbestos boards have many uses.

2. The **Ceiling** should also be painted white, so that the use of reflected light becomes possible; but no material should be used that is likely to become flaky.

3. The **Floor** is probably best constructed with a final covering of thin concrete, or, better still, a magnesium oxychloride mixture, as being non-inflammable, and resistant to practically everything that may fall on it. Linoleum or, perhaps, wood blocks may also be used where lighter forms of work are done. A channel near the wall should be supplied to carry off the water used for its cleaning.

III. Fittings.

1. **Benches.** The arrangement of benches depends on the size and shape of the space available, but all windows should not be taken up by them. Those that are should be provided with means for the immediate deflection of drafts in addition to the shields round the apparatus. Movable benches are frequently useful when apparatus has to be worked from more than one side. The usual teak, lead, tile or linoleum surfaces may be used, but they are not recommended when resistance to solvents and heat, permanence of level, and ease of cleaning are required with a minimum of expense. According to the nature of the operation to be carried out upon it, a surface of wood covered with stiff aluminium sheet, or of some magnesium oxychloride composition, may be adopted. Distillations that need not be done in the Distillation Room are best carried out over a tray of zinc filled to the depth of an inch with dry sand.

All bright metal parts and fittings should be chromium-plated ; and cellulose paint is preferable to oil paint.

Water, gas, and electric power points should be plentifully supplied.

2. **Fume Cupboards.** The floor should consist of some kind of tile or of slate, surrounded by an internal channel. The draught is usually accelerated by means of a gas jet, which is frequently insufficient, or by a fan, which is preferable. In both cases metallic corrosion is rapid, and there is little or no reserve whereby to combat down-draught. Some form of air injector, operated by a fan out of the way of corrosive fumes, is the best if not immediately the cheapest.

Fume chambers are seldom adequately illuminated. Light should be installed that shines on to the object and not into the eyes of the operator ; and all fittings must be specially protected from steam and acid corrosion.

3. The **Blow-pipe Table** should be placed in a dark corner.

4. **Pipes.** All piping should be immediately accessible, in case of trouble ; it should not be brought under the flooring unless very easily uncovered, nor behind or beneath benches.

In certain cases, where benches are in the middle of the laboratory, it may be convenient, at the sacrifice of appearance, to bring the service pipes overhead and vertically downward to the bench.

Gas and water pipes and other pipes and conduits should be painted distinctive colours : a British Standards Specification (457 : 1932) covers this matter.

Gas pipes along the benches should be of large diameter, even 2 in. ; so that if one gas cock is turned on or off, the pressure of gas to the others is not noticeably disturbed ; a governor may sometimes be preferable.

The waste pipes from the bench sinks should have trap boxes immediately below them. The exit pipes from these should be of the form of open gullies, so that any tendency to a stoppage is immediately found ; a disadvantage if there is the possibility of overflow.

Metal piping carrying carbon disulphide or other non-conducting liquids should be electrically earthed.

5. **Heating.** The most satisfactory method is undoubtedly by hot water, as it provides a distributable heat with no bare flame or incandescent wire. If the door of the Distillation Room is far from a naked source of heat, and if the room is well ventilated, the risk of ignition of heavy vapour rolling along the floor when some kind of stove or open electric fire is used, is not great, but should always be kept in mind.

6. **Illumination.** Electric light, properly spaced and distributed is undoubtedly the best. ' Daylight lamps ' are to be recommended, especially when titrations are carried out. Numerous points should be available for local illumination. Pocket electric torches are often extremely useful.

7. **Ventilation.** Ventilation without draughts is essential so that the various tests are not disturbed. Ordinarily, this is best effected by exhaust fans placed high in the laboratory and away from the window. In the Distillation Room, however, the exit is best placed at the level of the floor, as the heavy carbon disulphide and other vapours fall rather than rise. It must be remembered that most solvents customarily used are injurious one way or another : carbon disulphide is poisonous ; chloroform is an anæsthetic ; trichlorethylene also tends to produce sleep ; benzene and toluene dissolve the fat from the skin.

IV. Services.

1. **Gas.** In conditions where gas is not available, petrol-air gas or acetylene may be installed. It must be remembered that both these flames are much hotter than coal gas flames. In the field, a blow lamp may be used with discretion.

2. **Electricity.** As large a proportion of electricity as possible should be used on account of its convenience and the minimum chance

of ignition of volatile solvents. Wiring, when first installed, should be considerably heavier than may be considered necessary, to allow for subsequent developments. A constant voltage device controlling the laboratory may be necessary when fluctuations are greater than laboratory operations permit.

3. Water. A direct supply, with the laboratory tank as a stand-by for emergency, is the best on account of the degree and constancy of pressure, and uniformity and lowness of temperature.

These notes and comments might be extended considerably, but attention has been called to the more important points.

In addition, the following should be noted. When using inflammable and volatile solvents, the *risk of fire* is considerable, though trouble very seldom occurs owing to the care customarily exerted by a laboratory staff. This risk is diminishing, owing to the use of non-inflammable solvents for routine purposes; the use of fireproof materials in construction and fitting. Means for coping with any outbreak must be immediately available; buckets of sand should stand in the most available positions in the laboratory. Water is generally worse than useless, as the burning material is usually light enough to float upon it; this, and violent spluttering, tends to spread the fire rather than to extinguish it. Chemical extinguishers should be immediately available. They should be tested at least once a year; and should be examined, more frequently than this, to ensure their being charged and their nozzles being free from dust. Small stores of carbon disulphide should be stood in a deep vessel of water, so that there shall be no vaporization from any leakage.

In some cases, *protection against noise* is necessary. Certain machines, such as mechanical sievers, are nerve-racking when worked for long on end, and a sound-proof cover or chamber is essential.

When a laboratory is established and *distillations* are carried on, the Department of Customs and Excise (Headquarters: Custom House, Lower Thames Street, London, E.C.3) must be notified. This is a matter of law, but is usually only a formality, as the visiting Inspector realizes the operation and needs of a scientific and technical laboratory.

First Aid sets must be provided and fully maintained. Carron oil should not be used for burns, as it may not be aseptic.

The *routine examination* of samples is facilitated by the card system. Each separate incoming sample must be given a consecutive number; and details of nature, origin, date, etc., should be entered. The card is printed suitably for the entry of these and of the results of all the operations, carried out on the sample. It accompanies the

sample through the laboratory, and is only separated from it when the card goes in for reporting and the remains of the sample go into store. Different-coloured cards for different materials, and 'flags' for indicating specially interesting samples are useful.

Each laboratory must work out a system most suitable to its requirements, but examples of such forms that are in current use are to be found in Appendix VIII.

A method for the rapid collection of results for purposes of comparison or statistics has been described ³⁷⁸; it is an adaptation of the big-scale enumerators.

A record of *Laboratory Methods of Analyses* should be kept continuously up to date. All rough notes should be made in a notebook and not on scraps of paper; this is the only way to trace back errors.

In carrying out the routine work connected with the various localities where construction is going on, samples taken for examination are sent to the laboratory, and, unless postal and laboratory resources are unusually well organized, two days may elapse before a report on them can be received on the job as to the process of manufacture. To obviate this several types of *travelling laboratory* have been designed ³¹, fitted up in a standard living van, which can remain and operate on the site of the work to be controlled.

Staff. The Head of the Laboratory should be a qualified chemist fully conversant with his subject, and with a wide range of scientific knowledge (it is remarkable how valuable such broad interests frequently are to a laboratory of limited activities). He should be supported by a junior of the same type, capable of taking his chief's place when required to do so. The more qualified men the laboratory can support, the more valuable will be the work that can be done.

The number of trained but not necessarily qualified assistants depends on the nature and the amount of the work; but an attempt should be made to attract as high a grade as possible, as investigation work is continually required, and an intelligent rather than a dull routine worker (though both may do their routine work adequately) is a valuable reserve to draw on.

The road engineer finds little place in a works laboratory except for extending his own information. For this purpose he should be welcomed; but the advantage to the laboratory would be small, as close contact with practical operations should be maintained by frequent inspections of work by members of the laboratory staff.

Records of Daily Work.

It is desirable that, in connection with important road works, full record of daily operations should be entered on a road plan, record-

ing such particulars as the area laid with reference to such landmarks as numbering of houses, lamp-posts or telegraph posts, bench marks, etc. ; position from where samples were taken ; annotations regarding cold loads, weather, and all other facts valuable for future examination into the history of the road.

SAMPLING AND TESTING

Sampling

Bituminous Materials.

Sampling is of two kinds : there is (a) the delicate matter of obtaining a small sample that truly represents the nature and quality of a large bulk ; and (b) the removal, unaltered, of an area of road surfacing for transmission to the laboratory.

A great deal of attention has been given to this subject and the results have been standardized, so far as it is possible, in the methods published by The Institute of Petroleum, the Standardization of Tar Products Tests Committee, and B.S. 598 : 1940. When dealing with the removal of large road samples, it is unfortunate that no warning or instructions are given regarding care to be taken against cracking or fracture.

Concrete.

The sampling of the cement and aggregate that make up the concrete are given in the various controlling specifications, and need not be repeated here.

Tests

General. The correct principle underlying the testing of materials is the reproduction, as nearly as may be practicable, of those conditions that will be met with in practice. A close imitation is often impossible, or is so clumsy and expensive as to be left unattempted, but there are many tests that give useful indications of the quality of the material or of the service and behaviour that may be expected from it, even though their similarity to service conditions is relatively remote.

The more widely materials are used throughout the world, and the more extended is their commercial production, the greater is the necessity for their uniformity of quality for assigned purposes and of the means for ascertaining this. Many methods for chemical, physical, and mechanical testing have been put forward ; relatively few have survived detailed examination and prolonged experience, and fewer still have been adopted as national and international standards.

This does not mean that those methods which have not been standardized are valueless. Many, without doubt, are useful in individual laboratories or for particular purposes, but may not have had a sufficiently wide application, or may not be susceptible to those rigid limitations necessary for their being relied upon in a law case.

Great Britain is well supplied with scientific instrument designers and manufacturers, and their products are first class.

Bituminous Substances

The tests for tar and bitumen may be considered together as they have much in common. Many have been standardized by the Institute of Petroleum ¹², and the Standardization of Tar Products Tests Committee ¹³; and such of these as are required by the British Standards Institution have been adopted directly.

These publications must be studied for details, but comments on them and references to other useful tests are desirable.

Adhesion is the property by which stripping by water is resisted. Its importance is shown by the widespread attention which is still being paid to it in England ⁴⁴⁰ and elsewhere. The test consists in soaking or boiling the specimen in water alone or containing increasing amounts of sodium carbonate. There are unexpected difficulties in devising a standard test or even in agreeing upon the best line of approach to one.

Asphaltenes (Hard Asphalt) (I.P.T.—A.12).

It has been suggested, from time to time, that ethyl ether should replace the standard light petroleum for the determination of this constituent. The advantage is that the ether is a single substance, easy to obtain pure, and recoverable in a state of constancy of composition, whilst the petroleum spirit is a mixture and may vary on recovery. The suggestion has always been discarded on the ground that in hot countries ether is almost a vapour and is therefore unsuitable as a standard solvent.

Brittle Point. A useful test has been developed by Fraass, in which a film of specified thickness of the material is applied in a thin strip of steel, and the temperature of the breaking point is noted during repeated bending in a falling temperature ⁵⁸¹. A somewhat similar test, in principle though with a different technique, employs a rubber supporting strip.

Colorimetry. The deep colour of bitumen and tar suggests that very accurate colorimetric methods might be developed for the quantitative determination of these bituminous substances; but, except in

one case, important results have not been obtained, except in connection with accelerated weathering tests.

Direct comparison instruments have been used in the determination of the amount of bitumen remaining in solution after adsorption experiments with various kinds of filler ²⁹. The Lovibond Tintometer has been employed for the examination of asphalt powders, and for distinguishing between Trinidad Lake and refinery bitumen ³⁵².

Photo-electric Colorimeters are valued because colour and degree of brightness are measured on the dial of a milliammeter, and not by the human eye, which varies with the individual and with the state of his health.

They are dependent on two kinds of photo-electric cell: (a) that in which light causes a change in the electrical resistance of the material that it falls on, such as selenium; and (b) that in which electricity is generated by the light falling on a light-sensitive substance, such as potassium, caesium, and some others.

The Photo-Bitometer ¹⁰, depending on the photo-electric cell, has been designed to give the percentage of asphaltic bitumen or tar in a solution. Red and infra-red rays are passed through the solution, and the quantity of light falling on the cell produces a current of electricity proportional to the quantity of bitumen in solution. Accurate results are obtained only when all operations including careful filtering or centrifuging are carried out in exactly the same way, and when the apparatus is calibrated for the particular class (residual or rock) of bitumen being measured, as natural bitumen, for example, is more transparent than others. When 10–20 g. of the carefully sampled material is dissolved in 100 ml. of solvent, the determination requires about half an hour and an accuracy of 0.1 per cent. is claimed. Experience shows that this method is more suitable as a rapid confirmatory test than as a substitute for the longer-established method, though valuable investigation work can be done with it.

The *Panchrometer* developed by the same company is an instrument of investigation, whereby the absorption by the bituminous solution of the colours of the spectrum is measured by a photo-electric cell actuating a milliammeter.

Consistency. This word has no precise significance for roadmen, and it is best reserved as a general term embracing the more definite conceptions of viscosity, penetration, and ductility.

The inter-relationship of these three tests has been studied and described ¹⁵, and great progress is continually being made under the name of Rheology. Penetration and ductility have been attacked as regards their value, but there can be no doubt that even separately

they give indications by which suitability for specific purposes can be determined, and of the two, ductility is the more sensitive; whilst taken together, they afford a good protection to the consumer as regards the quality of the material supplied to him.

As a result of some remarkable work done in Germany ¹⁶, there can be no doubt of the close fundamental association of these properties with the underlying one of viscosity: at a low temperature, when the substance is 'hard,' the penetration is nil, showing viscosity to have disappeared—this point is the solidifying point.

A study in consistency in relation to temperature has led to the conception of an ascertainable property of 'susceptibility.' This may take the form of:

$$\begin{array}{rcc} \text{Pen. } 100^{\circ} \text{ F., } 100 \text{ g., } 5 \text{ sec.} & & \\ \hline \text{Pen. } 77^{\circ} \text{ F., } 100 \text{ g., } 5 \text{ sec.} & \text{or} & \\ \text{Pen. } 115^{\circ} \text{ F., } 50 \text{ g., } 5 \text{ sec.} - \text{Pen. } 32^{\circ} \text{ F., } 200 \text{ g., } 60 \text{ sec.} & & \\ \hline \text{Pen. } 77^{\circ} \text{ F., } 100 \text{ g., } 5 \text{ sec.} & \text{or} & \\ \text{H at } 32^{\circ} \text{ F.} - \text{H at } 115^{\circ} \text{ F.} & \times 100 & \\ \text{S.P.} & & \end{array}$$

where H represents Hardness by the Fraass test

S.P. ,, Softening Point (Krämer & Sarnow).

Susceptibility has also been founded in a highly mathematical treatment of viscosity ⁴⁸⁹.

Density: see Specific Gravity.

Ductility. The ductility test became established after some years of suspicion and opposition. This important property is now recognized as indicating the ability of the material to 'give' without fracture; and, like that of viscosity proper, the temperature-ductility curve is of high significance to the stability of the finished road surface. This property, also, is not pure, as it depends on viscosity, internal cohesion, and surface tension.

Ductility rises with temperature to a maximum and then falls. It is found that this maximum is about 28–30° C. below the softening point of the material. It is possible, therefore, to investigate ductility, not at fixed temperatures but at temperatures related to that of the softening point, such as 15°, 35°, and 40° below it ⁵⁷⁷.

The standard method requires the sample to be tested in triplicate as experience shows that more reliable results are obtained than when the test is carried out in duplicate. It not infrequently happens that minute defects in the thread are caused by a trace of dust or an invisible bubble, and out of three simultaneous tests one result is often definitely higher than the other two. When only two tests are made, the chances

of obtaining a truly maximum figure is lessened. The greatest advantage of this test is derived by carrying it out at several different temperatures, including the standard temperature of 25° C. so as to obtain a complete curve. (See also ⁴⁴⁷.)

Plasticity, which may be interpreted as a phenomenon of shear, has been linked with viscosity and penetration.

Softening Point. This is sometimes thoughtlessly spoken of as being 'melting point.' There is not and, indeed, cannot be a melting point of a mixture such as bitumen. On being heated it continuously softens, and its 'softening point' is the temperature at which some occurrence takes place depending on the apparatus used, so that it is, therefore, arbitrary.

The most commonly used test is the *Ring and Ball*, which has been standardized. In order to deal with a large number of routine samples with, it is claimed, greater consistency in results, a modification has been made in Hersberger and Overbeck's method. This, in principle, is a reversal of the standard method: instead of raising the bath temperature at a steady rate and recording the temperature at which the ball drops 1 in., the time is taken for the ball to drop 1 in. at a constant temperature ⁵⁷⁵.

A test much used at one time was the Krämer-Sarnow, in which a plug of the material under test supported a measured quantity of mercury in an open-ended glass tube. The whole was heated in a water-bath, and the temperature noted when the weight of the mercury forced the softened plug out of the tube. The test slowly fell into disuse owing to the difficulty of measuring the exact weight of the mercury at laboratory temperature.

Ubbelohde's test ⁶⁶ is well known in Germany and is not unknown here. It consists of a thermometer of which the bulb fits into a metal sleeve, and comes into contact therein with the sample, held in a glass cup which has a small hole in the bottom. The assembled apparatus is immersed in gently heated water. The softening point is taken as being that temperature at which the sample escapes completely from the cup.

The *Float test* consists of a light metal dish provided with a central hole plugged with the material to be tested. It is floated on heated water and the temperature of this is noted when the plug gives way and the dish sinks. It has been standardized in America, but is not used here.

Specific Gravity is the link between weight and volume; it is used for purposes of calculation and for identification. It is obtained by dividing the mass of a given volume of the substance by the mass of an equal volume of water; and as both of these expand at different

rates, the temperature at which both are measured must be stated. It is frequently and erroneously taken as being synonymous with **Density**, which is the mass of a body divided by a unit volume, usually in terms of grams per millilitre. This is a much more fundamental and simple conception and, therefore, to be preferred ; but, for the time being, specific gravity seems to be too well rooted in industry to be replaced. The relation between the two is :

Density at t° = sp. gr. at t° \times density of water at t° .

The choice of suitable apparatus depends on the scale on which work is to be carried out. When only a few samples are examined at a time, the displacement method is best for solids, and the hydrometer, pycnometer, or Westphal balance for liquids, according to circumstances. For rapid work on a large number of samples, an automatic instrument ¹¹ may be required.

'Free Carbon.' This substance is no longer looked upon as consisting of carbon, but as a substance in which carbon is present in high proportion. Its great importance lies in the 'body' given to the tar. Much work has been done on it by F. J. Nellensteyn.

Naphthalene. The limitation put on the proportion of this substance is due to its effect of lowering the viscosity of the tar, and also of causing change in properties by volatilization after the tar has been laid on the road.

Paraffin Wax. The difficulty attending accurate investigation is the inadequacy of the methods of analysis. There appears to be no definite analytical differentiation between crystalline paraffin wax and the amorphous seresin ('proto-paraffin'). The latter is transformed into the former by the heat required by the distillation method, and is ignored by the sulphuric acid method with its subsequent extraction and crystallization.

It is not surprising that neither method invites full confidence ; but so far the large amount of work that has been done, mainly in Germany has led to the preference of the sulphuric acid method of Schwarz. In this country, the distillation method of Littlejohn and Thomas ⁵¹ has been recommended after consideration of the existing methods. (See also ²⁰⁹.) A later and somewhat elaborate development by Müller and Wandyz is based on the use of pyridine at 0° C. ²²⁸.

Penetration. This is a valuable watch-dog test for the hardness of material supplied, but its inner meaning is not easy to trace owing to its complexity. The entry of the loaded needle into the sample is determined by the friction between the steel-bitumen surfaces, together with the viscosity which controls the movement of the mass making room for the volume of the entrant needle, and the action of surface

tension influencing the first moment of entry of the needle and the subsequent movement of the material.

The older 'No 2 Sharps' needles (still used for routine work) have been replaced by a slightly blunted standardized needle. This is identical with the American needle within the limits of the tolerances, but the English mode of description is considered to facilitate manufacture and standardization without sacrifice of accuracy.

The exact time of cooling of the sample before test must be adhered to, otherwise irregular results will be obtained.

Results are sometimes erroneously reported in 'degrees.' The measurement is made in 100ths of a centimetre, and it is difficult to see why, from the first, results were not expressed in $\frac{1}{10}$ mm.

The instruments employed for this test are well known. Attempts have, from time to time, been made to eliminate the personal error by making the apparatus entirely automatic. A successful instrument of this kind was devised in which the results were read by means of a vernier, ¹⁰⁵ (Fig. X1.2). Further improvements have been made.

Sulphur. This can be determined by oxidizing the material with nitric acid in presence of perchloric acid or bromine, and precipitating as barium sulphate.

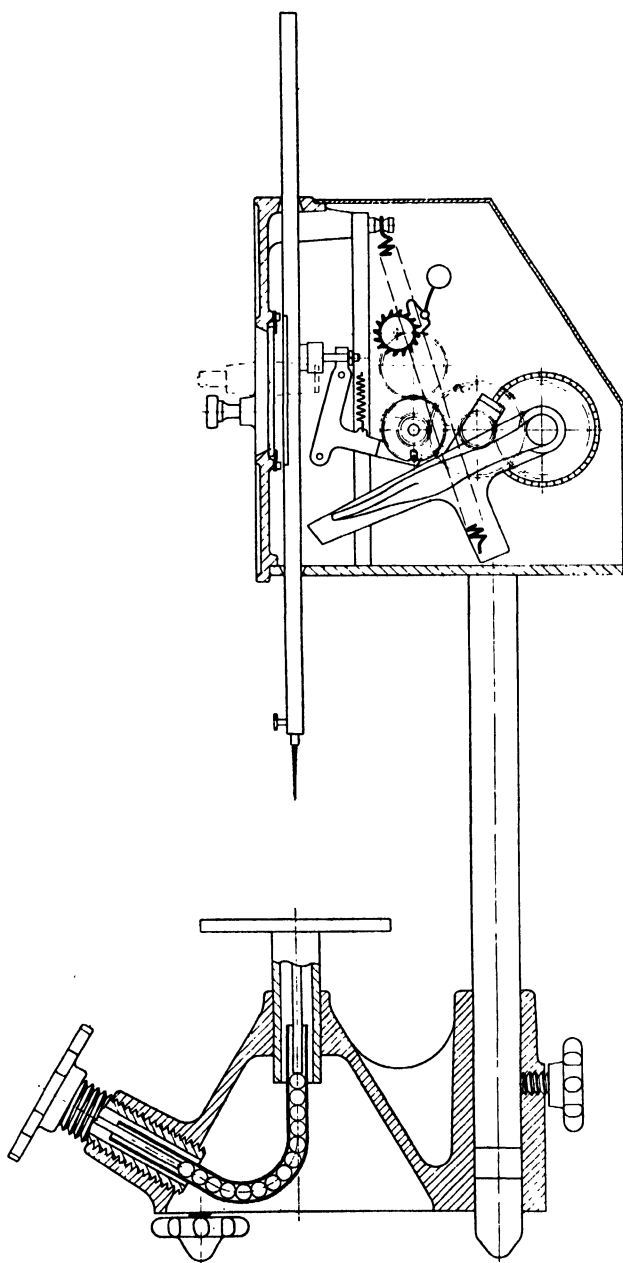
Tar Acids. A watch is kept on these compounds as they are suspected of poisoning fish life in ponds and streams.

Viscosity is one of the determining factors in the ease and completeness of flow and mixing in the plant, of spreading of mastic under the float, and in the stability to movement of the bituminous road surfacing. It is the external expression of the degree of attraction and internal friction between the molecules and complexes that constitute the material, and is a measure of its resistance to flow.

This study, which is complicated by elastic properties, has shown that tar and pitch are viscous liquids, and that asphaltic bitumen is a plastic solid ^{111, 112, 401}.

Most important and fundamental work has led to co-ordination, through viscosity, of the Softening Point (Ring and Ball, and Krämer-Sarnow), Drop-Point, Penetration, and Flow Test, of both bitumen and tar ²⁴². And all these are related under the term Rheology, which deals with the flow of matter under stress.

An interesting attempt has been made to develop further the significance and usefulness of the property of viscosity. Among tars, specific gravity varies with viscosity and chemical nature. As high and low aromatic tars have a relatively high and low specific gravity, a correction applied to the viscosity could express the nature of the material. Therefore, the 'real' specific gravity of a tar of fixed



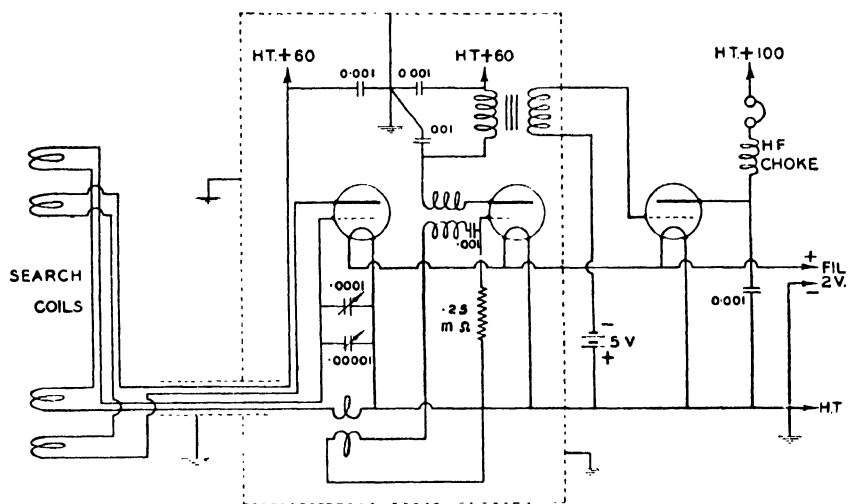
By the courtesy of Hutchinson's Testing Apparatus, Ltd.

FIG. XI.2.—Automatic Penetrometer.

viscosity—as expressed as E.V.T.—would indicate, through a graph, the origin of the tar ²⁰⁸.

Viscosity is measured by the resistance offered to the fall of a solid body through the liquid (as established by Stokes), or by the fall of the liquid past a solid body, i.e. through an orifice of a definite size in a container of a definite shape, starting from a definite depth.

Of the first type, there is the *Falling Ball* viscometer. This has long been known (see B.S. 188 : 1937) ; but it has been re-examined, and supplied with a thermionic valve circuit (Fig. XI.3) to indicate the position of a steel ball in its passage through the opaque liquid



By the courtesy of Hutchinson's Testing Apparatus, Ltd.

FIG. XI.3.—Thermionic Circuit Diagram of Falling Sphere Viscometer.

This has been named the 'Audio-viscometer' ²⁸, and is found to be trustworthy. The sensitivity has been much increased by the use of two separate circuits, adjusted to cause an audible heterodyne note ¹⁹.

The *Steiner* viscometer has developed the falling sphere into two types of instruments, using a rolling sphere or a rising bubble.

L. Steiner has developed commercially a number of interesting viscometers. There is also the *Hutchinson* instrument, which consists of a weighted float adjusted to sink at a slow rate. It has been widely used for a long time, but it lost ground before newer instruments, on account of (a) its having an arbitrary and no discernible scientific basis ; (b) the necessity for adjusting accurately the temperature of a relatively large quantity of material ; and (c) the erratic variation of results between various instruments and during the life of an instrument. The last two disabilities have been to a great degree overcome

in the redesigned *Junior* instrument. The most important instruments are the *Redwood No. II* for asphaltic bitumen, and the German *Engler* viscometer for asphaltic bitumen and emulsions, and the specially developed *Tar Viscometer*. Thus the *Hutchinson* instrument is becoming gradually relegated to the plant and roadside.

The *U-tube Viscometer*, as it is known by the British Standard 188 : 1937, and by laboratory workers as the Ostwald Viscometer, has been worked out to give absolute viscosity directly. It has been criticized regarding the degree of accuracy attainable ⁵⁶. This type of instrument has been modified, at the Chemical Research Laboratory at Teddington, for use with tar and similar materials over a wide range of viscosities. The pressure to cause flow is obtained from a column of mercury ⁴³⁰.

The *Tar Viscometer* (British Road Tar Association) has found wide recognition abroad, including Germany, where, unfortunately, it has been called a 'consistometer'—unfortunately, because the word has for some time been used in America for a kind of penetration machine.

An elaborate examination, both practical and theoretical, of the *Hutchinson* and the British Road Tar Association instruments was carried out on six tars at the National Physical Laboratory ²⁴¹. Duplicate tests with the *Hutchinson* instrument varied to 5 per cent. The tars showed true viscous flow, a result also reached by Evans and Pickard ¹¹¹, but were subject to irregularities of a complex nature. The approximate relationship between the two instruments, in terms of absolute viscosities, was found to be complicated :

$$\eta = K_H T_H (M - V\rho) = K_R T_{RP}$$

where η = the absolute viscosity in poises

K_H = a constant, 1.67 mean

T_H = *Hutchinson* time in secs.

M = Mass of the *Hutchinson* tester

V = Volume

ρ = Density of the tar

K_R = a constant, 44.4 mean

T_R = B.R.T.A. time in secs.

But as the results showed that viscosity at 25° was 1.9–3.0 times that at 30°, it is impossible to connect accurately *Hutchinson* times at 25° with B.R.T.A. times at 30°.

Mallison's Tar Tester ^{64, 65} is a rapid method for checking viscosities to within 5 per cent. of its true value. The samples are warmed in test-tubes to the required temperature, and inclined at an angle ; and their length of flow is measured after a particular time. This length is then referred to a calibration curve for translation into viscosity

units. Another method of use is to test the unknown sample simultaneously with one of known shorter time of flow and one of longer; and a close approximation of the viscosity of the sample can be obtained.

A recent method of measuring viscosity in the form of a Flow Test on somewhat similar lines, consists of filling the shorter tube of a hollow L-shaped container with the sample, and placing the instrument, with its filled limb vertical in a controlled temperature. The rate of flow into the empty limb enables relative figures to be obtained ²²¹.

The series of *Metro* instruments—Frough Viscometer, Plastimeter, Capillary Tube Viscometer, and Rotating Cylinder Viscometer—have been developed for testing and investigating tar, pitch, and asphaltic bitumen over a very wide range of consistencies ^{111, 112}. They give results that are directly in, or are easily calculated to, absolute viscosities; and correlation with existing commercial instruments has been established. A valuable series of instruments has been made available. A concentric cylinder viscometer has been developed by the Limmer & Trinidad Lake Asphalt Co., Ltd., more suitable to research than routine purposes ⁵⁷.

(For a general discussion of the underlying theory of the inter-equivalence of these various instruments, see ³³⁷.)

It must be remembered that all these tests, with their various degrees of excellence, are 'slow-motion' tests—they are applied to the material during relatively long periods, as compared with the sudden stresses of a passing motor-omnibus. This opens the question as to how far the current viscosity tests simulate in sufficient degree the conditions on the road; and also the far wider question of what happens, in complete detail, in a road surface.

So many interesting instruments have been developed that it is impossible to refer to them all in a book of this nature.

For a very full examination of the whole subject, see ⁵⁸².

As a control method, a sample of tar for examination for viscosity may be separated from tarmacadam, without the intervention of a solvent, by means of the centrifuge. 100 gr. of the sample is contained in a cup (of B.S. alloy L33) on 200-mesh gauze, and centrifuged at 1,000 to 1,200 (usually about 1,200) r.p.m. at about 120° C. ³⁹⁹.

The *units* in which viscosity is measured vary: the Redwood (British) and Saybolt (U.S.A.) and others give their results in seconds of different standard effluxes, and the Engler (German) in degrees. Interconversion equations and tables are available; but there is a growing preference for the expression of viscosity in terms of the more fundamental kinematic viscosity, of which the unit is the Stoke. A squared paper chart is available for instantly effecting interconversions ⁴⁶³.

In the case of the Tar Viscometer the relation (for a horizontal retort tar) is: Kinematic Viscosity = 4.4 (B.R.T.A. seconds, at 30° C.)⁶⁷.

The tars which are used for road construction cover a wide range of values. Therefore a system has been devised whereby a convenient and sufficiently accurate designation can be given. This is known as

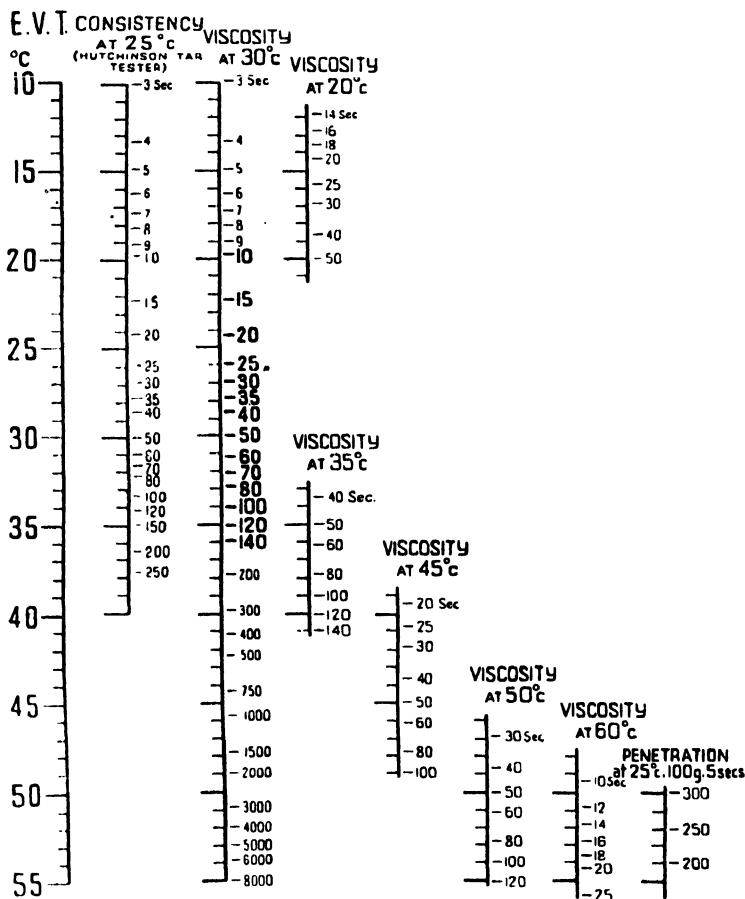


FIG. XI.4.

the Equi-viscous Temperature—the temperature at which the tar has a viscosity of 50 secs. when measured in a standard fashion. There are considerable advantages in this: the avoidance of large numbers which have little significance; a regular relation between the viscosity and measurement in seconds; and a clearer significance of the results of blending and fluxing²²⁸.

The point of these is shown in the chart (Fig. XI.4).

Changes in viscosity with temperature are most important for the manufacture and stability of bituminous road mixtures. A steep temperature-viscosity curve means that at raised temperatures mixing is easy and when laid and cooled the surfacing is firm and immovable. But if the slope is too steep, separation of components may become easier than their mixing, and a small rise in temperature may cause the laid mixture to move considerably under traffic. A straight line relationship has been found to exist between log viscosity in poises and log temperature in °F., which holds good over a large range of tars and viscosities ⁴²⁸. The change in temperature-viscosity relations throws valuable light on the internal constitution of tar-bitumen mixtures (q.v.).

An excellent pamphlet on the subject has been published by the Department of Scientific and Industrial Research ⁴⁰¹; and by the British Road Tar Association in 1946.

The whole question of viscosity was discussed at the World Petroleum Congress, in 1933.

Viscosity and Thixotropy. The pure phenomenon of viscosity exhibits movement in proportion to the applied shearing force, and is known as Newtonian viscosity. In some cases these are not proportional to one another, and their numerical relations change with time and are dependent on the past history of temperature and manipulation. These variations are due to structures which are formed within the colloidal mixture and form the study of 'thixotropy' (see ²²⁷).

Bituminous Mixtures

The Sampling and Examination of Bituminous Road Mixtures, B.S. 598 : 1940, is a revision of the first edition of 1936. It regularizes the Pat Stain Test, Specific Gravity, Voids, Soluble Bitumen Content, and the examination of the Mineral Aggregate. It is of interest, too, as containing a suggested Form of Certificate of Routine Analysis.

Recovery of Asphaltic Bitumen from Asphalt Mixtures. For a long time it was difficult to recover the bitumen from mixtures in the same condition in which it existed in the road. Changes were found to have occurred during the operations of solution, filtering, and removal of the solvent by heat. Much work was done on this abroad; but the earliest success here was that of Wilson, which depended on particularly careful filtering and the removal of the solvent in four stages—by distillation, on a water bath, in boiling water, and in an oil bath. Typical results are given in the Table on p. 368.

Much work has been done to improve the method, partly by the choice of the solvent, but mainly through the use of reduced pressure

during the final distillation, together with the passage of CO_2 ⁴³³. Both low- and high-vacuum methods are included in B.S. 598 : 1940 ; and more rapid methods for routine purposes have been worked out by Chalk ²³¹. (See also ⁴⁹⁴.)

PENETRATION

	Samples.			
	1	2	3	4
Before solution and recovery . .	64	82	25	35
After recovery	65	81	26	37

	BITUMEN TYPE A.		BITUMEN TYPE B.	
	Before Recovery.	After Recovery.	Before Recovery.	After Recovery.
Penetration at 25° C.	64	66	43	43
Ductility at 25° C.	+ 100	+ 100	79	31
Melting point (B. and R.) ° C.				
Softens	33° C.	35°	44° C.	41° C.
Melts	56° C.	57	61°	61°
Viscosity (Engler) at 200° C. (time of outflow of 100 ml.)	173 secs.	176 secs.	127 secs.	140 secs
Loss on Heating (5 hours at 200° C.)	0.4%	0.58%	0.2%	0.1%
Penetration at 25° (after heating test)	50	42	26	26
Ductility at 25° C. (after heating test)	+ 100	+ 100	9.5	12

A rapid method of analysing bituminous road mixtures for routine purposes has been worked out at the Road Research Laboratory, which involves the use of methylene chloride as solvent. An aliquot portion of the filtered solution is evaporated under reduced pressure. The time required is about 30–90 minutes. The differences between the results by this method and by the standard method vary between 0.0 and 0.2 per cent. ⁵⁴⁵.

Much work has been done in the examination of small sources of error, such as in laboratory sampling, presence of water, adsorption of bitumen by the mineral aggregate, the use of solvents which enable more rapid working. Also, the tracing of faults in the control of manufacturing and in plant operation ⁴⁹.

Rapid and more complete separation of the dissolved bitumen

from the mineral aggregate is especially desirable when volatile oils are present, or when exposure has increased the insoluble matter. In these cases, a centrifugal method is recommended⁵⁸⁴. The older form of centrifuge was most unsatisfactory (though it lasted quite a long time in America) on account of vibration which caused rapid wear on the bearings, and of the ease of escape of carbon disulphide into the driving motor.

A test for the suitability of a *jointing material* is to let fall, from increasing heights, a 50-gr. ball on to a layer of the sample after it has been kept at 0° C. for 2 hours (German); or to let the ball fall on the back of an iron plate on which has been spread the sample in a layer of 5 mm. thick (Shell). In either case, the height of fall of the ball when the material cracks or separates is the critical figure.

Emulsions

A laboratory set up for dealing with emulsions must be prepared, more than any other road laboratory, to carry out routine and research work on the lines of a university or technical college, rather than that of a works. This will not be considered to be an exaggeration when it is remembered how readily emulsions respond to small influences such as, to give a single example, any deviation from a scrupulous cleanliness of containers or apparatus, unknown (and unnecessary) in an asphalt laboratory.

The testing of emulsions need not be considered here, as they are covered by the Specifications and by *Modern Road Emulsions*. But reference might be made to a circular testing track, which one important firm has constructed, in order to study the behaviour of experimental mixtures on a miniature road.

Viscosity. The Stormer (revolving cylinder) instrument is used, though not 'officially'; also the pipette viscometer, which is capable of considerable accuracy; and 'local' funnel instrument.

A 'micro-Hutchinson' glass sinker is also used. This is of additional interest, as it is so small that, as an instrument, it is half-way between a viscometer and a penetrometer and so indicates the fundamentally close general relationship between the two properties.

*Strength of Bitumen Film*³⁴⁸. A film of bitumen of known thickness is produced between two sides of a steel wedge and two steel blocks between which it fits. All contact surfaces are highly polished, as well as the lower ones of the steel blocks which also are lubricated. Pressure is exerted on the wedge, and the force required to produce movement—that is, to break the film by shearing—is measured. Increase of thickness of film leads to a rapid decrease in its strength.

Mineral Aggregate

Sampling and examination have been regularized by B.S. 63 : 1939 and B.S. 812 : 1943 which deals with aggregate generally, by B.S. 882 : 1944 with the aggregate for concrete ; whilst B.S. (War Emergency) 1047 : 1942 controls the nature of acceptable slag, and B.S. 1165 : 1944 that of clinker. Therefore, only comments are needed.

Sieve analysis is carried out with B.S. standard sieves (410 : 1943) in which the successive sizes of openings increase by $\sqrt{2}$ measured along the side of the square aperture.

“ The order in which the sieves are used shall be stated in reporting results ” ; and “ When sieving material on sieves increasing progressively in size, the material shall first be passed over a 7-mesh B.S. test sieve to effect preliminary separation.” These two sentences show cautious handling of contrary conditions. If the finest sieve be used first and the coarsest last, continuous grinding of the particles may produce a further proportion of fine material which may lead to erroneous results ; and also the finer sieves may become unduly worn. At the same time, this order has the advantage of removing the fine material which might be carried away adhering to the larger lumps.

In the past the designation of the sieves has been misleading as it was based on the number of apertures to the inch, irrespective of the size of wire employed. A Table of modern designation and sizes is given. For accurate work considerable care must be taken to guard against changes in the sieves. Wear and rough usage tend to accentuate the effect of any error that may result from slightly faulty weaving of the wire mesh ; and that any such fault may exist is acknowledged by the tolerances allowable to the standard sieves. When a number of sieves are in use, one set should be kept as a standard of reference, and routine results should occasionally be compared with those of the standard kept in reserve. Or, all sets should be compared from time to time with a standard sand kept for the purpose. In particular is this the case with the 200-mesh sieves and finer.

Direct measurement of the sizes of particles can now easily be made under the microscope by means of a graticule in the eye-piece ²⁴⁷.

Road-stone (see also ⁶⁰³).

Great value results from *microscopical examination*, and this has been developed by the Geological Museum, Exhibition Road ¹⁴² (previously the Museum of Practical Geology, in Jermyn Street, London) ; by E. Morton ¹⁵⁴, by Dr. Bernard Knight, and in the laboratory of the Limmer & Trinidad Lake Asphalt Co., Ltd. Such work makes clear the identity of the material, and the suitability for road work depending on the cracking and decomposition that may have occurred.

The far-reaching examinations carried out by this firm is seen in the recording forms used (on p. 426).

Road-stone is also tested for shape of particle, as flaky and elongated material is structurally weak ; shape and texture are also examined.

Shape of Particles. The importance of this to the stability of road surfacings has long been known, and caliper measurements and calculations of ratios were suggested by Walz in 1936 and Heywood in 1937. Later, Markwick developed clear conceptions of shape and rapid methods for their measurements which were accepted in B.S. Specifications ⁵⁰⁴. In addition, Clements's classification of shape and surface characteristics was also adopted ⁵⁰³.

Much work has also been done on the *Soundness* of road-stone, by soaking in a solution of sodium sulphate or magnesium sulphate and allowing crystallization to occur in the cracks of the specimen and so test resistance to strain. The test has not been widely adopted.

Road-stone, Crushing Strength : The Aggregate Crushing Test for Evaluating the Mechanical Strength of Coarse Aggregate.

Among the standardized tests for road-stone, the crushing strength is one of the most important. That which has been adopted has given satisfaction because of its ease of application, its reproducibility, and the close relation of its results to behaviour under traffic.

It has been shown ²³⁴ that its published limitations to aggregates of sizes $\frac{1}{2}$ in. to $\frac{3}{8}$ in. can be extended to 2-in. stone, and that this test can be very simply related to the Los Angeles test (a tumbler test using steel balls).

It is remarkable that so important a matter as the details of the operation of sieving should have remained so long neglected. In two *Notes* (1943 ¹⁰⁶ and 1945 ²²⁶) the Road Research Laboratory has given a valuable collection of practical details of which only a few can be mentioned. Clay should be removed by wet sieving. A particular motion of the sieve is the most efficient. The wire mesh of the sieve should be cleaned free from jammed particles with great care, using

a 2-in. wire nail for the $\frac{3}{8}$ in. and No. 7
stiff brush for the Nos. 14, 25, 52
camel-hair brush for the Nos. 100 and 200

The maximum safe load for each sieve is :

$\frac{3}{4}$ in.	. . . . .	3,000 gr.	No. 25	. . . . .	70 gr.
$\frac{3}{8}$ "	. . . . .	600 "	No. 52	. . . . .	50 "
$\frac{1}{2}$ "	. . . . .	400 "	No. 100	. . . . .	35 "
No. 7	. . . . .	150 "	No. 200	. . . . .	25 "
No. 14	. . . . .	100 "			

The ideal is to sieve with a layer one particle deep.

The use of automatic sieving machines is very attractive, but different results are being obtained by different machines ; and even when the same machine runs cold or gets hot during use. The problem has not yet been solved. The results of all this work is seen in the new revision of B.S. 812 : 1943.

There was so much discrepancy in the results of tests obtained with sieves constructed with round and square holes that B.S. 63 : 1939 for Sizes of Road-stone and Chippings was required to set the matter right, by superseding the specification of 1928. In effect, closely approximate results are now given by :

Square Openings.		Round Openings.	
2½ in.	as	by	3 in.
2 "			2½ "
1½ "			2 "
1¼ "			1½ "

In addition, the specification gives the tolerance permissible to single-sized material. For all technical and scientific purposes, it is of high importance that the user shall receive from the quarry material of the size he orders. Too often, road tests and laboratory experiments are partially or wholly nullified by the mineral aggregate being widely divergent from the required sizes. It is of urgent necessity that quarry managers should be continually watchful that their plant is kept up to the necessary efficiency and accuracy.

Further examination has disclosed unexpected irregularities, apart from changes normal to wear. Sieves of ½-in. to ¾-in. mesh have shown marked divergences in results when made of woven wire as compared with perforated plates—the former being as much as 4 per cent. bigger. Errors may be greater with the 2-in. sieves.

Further irregularities can occur if the quantities of material sieved are not strictly adhered to : 100–150 g. of coarse sand and 40–60 g. of fine ; because there is considerable variation in results according to the degree of loading of the sieve ⁵¹⁶.

A useful summary paper by Dr. Bernard Knight has been recently published ⁵¹⁰.

The standard specification states its requirements for dealing with *balling sands* ; but if this is very bad, the following method can be employed in a technical laboratory : 100 g. of the material should be mixed with enough water to be freely flowing, and poured in small quantities on to a weighed sieve. When all has been transferred, sieving is continued under a flow of water, insufficient in strength to cause splashing or subdivision of the material. When ended, the whole should be washed with methylated spirit, preferably from a wash bottle, to minimize the time of drying ; excess of spirit can be

removed by a cloth, and most of the remainder evaporated by gentle waving in the air. The sieve and contents are finally dried in an oven, at 200° C., for 5 mins. When cool the whole is weighed, and the difference between this weight and that of the sieve alone is the weight of the retained material. The whole operation can be completed in about 20 mins.

Mechanical sieving saves much time and energy, and has been standardized in America. Investigation is going on in this country, to improve the machine and its operation, because, at the present time, different machines give different results.

It is often found that the results obtained by hand sieving do not agree with those obtained mechanically; this is due to improper choice of conditions. If 200–500 g. of material retained on the 7-mesh B.S. sieve be mechanically sieved with brushes on the sieves the results will correspond to 50–100 g. of similar material sieved by hand.

Sieving results are calculated into percentages of material retained, of the weight of the sample. These may be recorded in the usual tabular form, or they may be plotted in squared paper. The latter is valuable in showing vividly any deviation from the required grading. Another method is the 'cumulative plot,' which consists in plotting, for each mesh size, the total retained up to that mesh. This enables the percentage retained by any particular mesh to be ascertained without that mesh having actually been used. The methods and applications of such plotting have been highly developed⁸, and are being increasingly preferred. (See also 'Fineness Modulus' under *Concrete*.)

The *standard sieves* of to-day have been evolved by long and arduous work. In this country they have been standardized in B.S. 812: 1943. A comparison of these with other well-known systems is shown in the Table on p. 374.

Sands.

Moisture. The direct and obvious method is to heat a known weight of a representative sample to constancy, and determine the loss. The following American method is useful when a source of heat is not available: 250–500 g. are put in a metal container; a little alcohol is poured on, and when percolation is complete it is ignited. The heat drives off the water and the loss in weight is determined. The layer of sand is best spread shallow.

Moisture determinations can rapidly be made by means of a balance supplied with the necessary container for the sample and special scales¹³⁷.

Another method is to determine the specific gravity of a liquid before the addition of a measured quantity of the wet sand.

COMPARISON OF TESTING SIEVES (all square mesh)
(*Modern Road Emulsions*, 1939, p. 207 (slightly modified))

Designation of Sieve.				Size of Aperture (in.).								
B.S.I.	A.S.T.M.	I.M.M. (new).	I.M.M. (old).	Tyler.	D.I.N.	B.S.I.	Approx. Fractional Equivalent.	A.S.T.M.	I.M.M. (new).	I.M.M. (old).	Tyler.	D.I.N.
240	—	200	200	—	100	0-0026	1/400	—	0-0025	0-00255	—	0-0024
200	200 [74]	—	150	200	80	0-0030	1/333	0-0029	—	—	0-0029	0-0030
170	170	150	150	—	70	0-0035	1/288	0-0035	0-0033	0-00355	—	0-0035
150	140	120	120	150	—	0-0041	1/240	0-0041	0-0041	0-00414	0-0041	—
120	120	100	100	—	50	0-0049	1/200	0-0049	0-0050	0-00485	—	0-0047
100	100 [149]	90	90	100	40	0-0060	1/165	0-0059	0-0055	0-00549	0-0058	0-0059
—	—	80	80	—	—	—	—	—	0-0063	0-0063	—	—
85	80 [177]	70	70	—	—	0-0070	1/144	0-0070	0-0071	0-00724	—	—
72	70	60	60	65	30	0-0083	1/120	0-0083	0-0083	0-00828	0-0082	0-0079
60	60	50	50	—	24	0-0099	1/100	0-0098	0-0100	0-00987	—	0-0098
52	50 [297]	40	40	48	20	0-0116	1/84	0-0117	0-0125	0-01243	0-0116	0-0118
44	45	—	—	—	—	0-0139	1/72	0-0138	—	—	—	—
—	—	—	—	—	16	—	—	—	—	—	—	0-0152
36	40 [420]	30	30	35	14	0-0166	1/60	0-0165	0-0167	0-01701	0-0164	0-0169
30	35	—	—	—	12	0-0197	1/50	0-0197	—	—	—	0-0193
—	—	—	—	—	11	—	—	—	—	—	—	0-0214
25	30 [590]	20	20	28	10	0-0236	1/40	0-0232	0-0250	0-0250	0-0232	0-0236
22	25	—	—	—	—	0-0275	1/36	0-0280	—	—	—	—
18	20 [840]	16	16	20	8	0-0336	1/30	0-0331	0-0313	0-0316	0-0328	0-0295
16	18	12	12	—	6	0-0395	1/25	0-0394	0-0417	0-0414	—	0-0402
14	16	10	10	14	5	0-0474	1/21	0-0469	0-0500	0-0513	0-046	0-0473
12	14	—	—	—	4	0-0553	1/18	0-0555	—	—	—	0-0591
10	12	8	8	10	—	0-0660	1/15	0-0661	0-0630	0-0620	0-065	—
8	10 [2,000]	—	—	—	—	0-0810	1/12	0-0787	—	—	—	—
7	8	5	5	8	—	0-0949	1/10	0-0937	0-1000	0-1026	0-093	—
6	7	—	—	—	—	0-1107	1/9	0-1110	—	—	—	—
5	6	—	—	6	—	0-1320	1/8	0-1320	—	—	0-0131	—

Sieve designations in heavy type are those commonly used in asphalt work in Great Britain and America.
Figures in brackets represent the size of the sieve openings in microns.

Cleanliness. A clean surface, free from adhering carbonate or hydroxide, can be identified on magnification, or by treatment with acid. The presence of free fine material is found by streaking on paper or by shaking with water. Organic matter is identified by the depth of colour produced by alkali. This can be quantitatively measured by means of the photo-electric cell ⁹⁸ or by a tintometer.

Colloidal matter is detected by staining with malachite green which is taken up by the clay, and the colour compared with standard colours of known depth. Or else, the sand is treated with ammonia and then with acetic acid, to clean the colloidal matter, and solid crystals of the dye are added, with shaking, till a green tinge remains permanently in the solution (Henry and Simmonds) ¹⁴⁴.

Voids. This test can be made by running water slowly upward through a known volume of sand that has been shaken or tamped into a vessel; the volume of water required to saturate the mass of sand being the measure of the volume of the voids.

When this well-known test is carried out, the moisture already present may be overlooked. The amount of the resulting error is to be obtained from the Table (p. 376) ¹⁸⁹.

The percentages of absolute voids given in the columns below include the space occupied by both the air and the moisture. To determine the percentage of air space, multiply the figure in the last column, opposite the weight of sand under consideration, by the percentage of moisture by weight, and deduct the result from the percentage of absolute voids already found.

A constant liability of error is the persistence of air pockets in the sand; and although this can be lessened by the use of carbon tetrachloride instead of water, the finer the sand the more difficult it is to secure complete permeation. At the same time there is the serious risk of fallacious results associated with compaction. Although it is theoretically true that the subdivision of a solid leads to the formation of a larger and larger number of smaller and smaller voids, whilst the proportion remains continuously the same, yet in practice the voids in sands ranging to filler show a change from about 30 to 60 per cent. of voids. If, however, a filler is heavily compressed the voids can be reduced to 33 per cent.

In a better method which avoids the error due to imperfect penetration by a liquid, but is still at the mercy of the effect of shape of particle and roughness of surface influencing the degree of settlement in the measuring vessel, voids are determined by a refined volume-weight measurement ⁹¹.

Filler. The reciprocal behaviour of filler and bituminous binder is a function of the sizes of the particles of the filler. It is therefore

TABLE
(reproduced by the courtesy of the Publishers ¹⁴⁴)

POROSITY OF MOIST SAND

Weight of 1 cu. ft. of Sand.*	Percentages of Absolute Voids in Material containing Moistures by Weight.					Moisture by Volume corresponding to 1% by Weight.
	0%	2%	4%	6%	8%	
70 . .	57.6	58.4	59.3	60.1	61.0	1.1
75 . .	54.5	55.4	56.4	57.3	58.2	1.2
80 . .	51.5	52.5	53.4	54.4	55.4	1.3
81 . .	50.9	51.9	52.9	53.9	54.8	1.3
82 . .	50.3	51.3	52.3	53.3	54.3	1.3
83 . .	49.7	50.7	51.7	52.7	53.7	1.3
84 . .	49.1	50.1	51.1	52.2	53.2	1.4
85 . .	48.5	49.5	50.6	51.6	52.6	1.4
86 . .	47.9	48.9	50.0	51.0	52.0	1.4
87 . .	47.3	48.3	49.4	50.4	51.5	1.4
88 . .	46.7	47.7	48.8	49.9	50.9	1.4
89 . .	46.1	47.1	48.2	49.3	50.4	1.4
90 . .	45.5	46.5	47.6	48.7	49.8	1.4
91 . .	44.8	45.9	47.0	48.2	49.2	1.5
92 . .	44.2	45.4	46.5	47.6	48.7	1.5
93 . .	43.6	44.8	45.9	47.0	48.1	1.5
94 . .	43.0	44.2	45.3	46.5	47.6	1.5
95 . .	42.4	43.6	44.7	45.9	47.0	1.5
96 . .	41.8	43.0	44.1	45.3	46.4	1.5
97 . .	41.2	42.4	43.6	44.7	45.9	1.6
98 . .	40.6	41.8	43.0	44.2	45.3	1.6
99 . .	40.0	41.2	42.4	43.6	44.8	1.6
100 . .	39.4	40.6	41.8	43.0	44.2	1.6
101 . .	38.8	40.0	41.2	42.5	43.7	1.6
102 . .	38.2	39.4	40.7	41.9	43.1	1.6
103 . .	37.6	38.8	40.1	41.3	42.5	1.6
104 . .	37.0	38.2	39.5	40.8	42.0	1.7
105 . .	36.4	37.6	38.9	40.2	41.4	1.7
106 . .	35.8	37.0	38.3	39.6	40.9	1.7
107 . .	35.2	36.4	37.7	39.0	40.3	1.7
108 . .	34.6	35.9	37.2	38.5	39.7	1.7
109 . .	33.9	35.3	36.6	37.9	39.2	1.7
110 . .	33.3	34.7	36.0	37.3	38.7	1.8
115 . .	30.3	31.7	33.1	34.5	35.9	1.8
120 . .	27.3	28.7	30.2	31.6	33.1	1.9
125 . .	24.2	25.8	27.3	28.8	30.3	2.0
130 . .	21.2	22.8	24.4	25.9	27.5	2.1
135 . .	18.2	19.8	21.4	23.1	24.7	2.2
140 . .	15.2	16.8	18.5	20.2	21.9	2.2

* The table is based on sand having a specific gravity of 2.6.

important to know the numbers of the various sizes of the particles (methods for ascertaining this are given below), and also to total area which the bitumen or tar has to cover. This area can be ascertained approximately by laborious calculation after the various sizes of particles have been ascertained or by an air-permeability method ⁴⁹¹.

The measurement of the size of fine particles and the study of their properties have given problems that have been deeply studied. The smaller the particle the larger is its surface in relation to its mass (and through this to the pull of gravity), so that the measurement of both these fundamental properties becomes increasingly difficult the more pronounced becomes their usefulness. Examination of the details of the work that has been done is beyond the scope of this volume, but a fascinating study is open to those who have opportunity and time for it.

Separation into the various sizes of fine particles can be effected by sedimentation or by elutriation. During sedimentation the particles fall under the pull of gravity, and the size can be measured in terms of turbidity by means of a photo-electric cell and a galvanometer ⁵⁰⁸. The Wagner method has won much approval. Elutriation ¹²⁷ consists in gravity being overcome by an upward stream of air ⁴⁴³ or liquid which facilitates the collection of the successively separated sizes of particles. (See also ⁵⁰⁹.)

The relation of the particles to the fluid through which they fall is given theoretically by Stoke's Law :

$$V = \frac{2}{9} \rho \frac{S_1 - S_2}{\eta} \cdot g$$

where V represents the velocity of fall

ρ	„	diameter of the particle
S_1	„	specific gravity of the particle
S_2	„	specific gravity of the surrounding medium
η	„	coefficient of friction of the medium
g	„	force of gravity.

Water is usually employed for these purposes, but when it is unsuitable a petroleum fraction such as kerosene is used.

There seems to be a tendency to-day to prefer sedimentation methods.

Bulk Density of Filler in Benzene. This important test is carried out as follows : 10 g. of the sample, dried for 3 hours in an oven at 120–150° C., is introduced into a boiling tube, about 15 cm. long and 2.0–2.2 cm. internal diameter, and calibrated in cubic centimetres. It is nearly filled with pure dry benzene. After boiling to expel air, it is left to cool at room temperature. It is thoroughly stirred with

a metal rod and allowed to settle for 6 hours. The bulk volume is read, and this divided into 10 gives the bulk density. An average of three separate determinations is taken ; but if a single value differs by 0.01 from the mean value, another 3 determinations must be made ⁴²².

Figures obtained by this method (1939) ⁵⁰⁰ :

	Density.	Bulk Volume per grm.	Bulk Density in Benzene.
Coal Dust	1.43	1.63	0.613
Limestone (1)	2.76	1.39	0.719
„ (2)	2.76	1.10	0.909
Slate (1)	2.87	2.03	0.492
„ (2)	2.57	1.53	0.654
Granite	2.52	0.85	1.176
Cement (1)	3.11	1.46	0.685
„ (2)	3.11	1.10	0.909

The first air-elutriator was the *Flourometer* of P. Mayntz Petersen, Head of the Copenhagen Testing Laboratory ³⁸. It was designed primarily for the examination of Portland cement, but it is applicable for use with other materials of similar nature. In recent years it has been neglected for no clear reason, so that its description is given as it is useful and simple in use. Each instrument is to be compared with a standard instrument in the Copenhagen Laboratory.

The shape of the vessel is shown in Fig. XI.5, and the dimensions and air velocity at standard pressure at the various cross-sections are given in the Table. By the introduction of a little smoke into the air

Point in Flourometer.	Diameter at : cm.	Cross-sectional Area. sq. cm.	Velocity of Air. ft. per sec.
Where T-piece branches to manometer	0.965	0.73	5.56
N	0.45	0.16	25.37
M	1.10	0.94	4.32
L	1.60	2.00	2.03
K	2.39	4.5	0.90
J	4.43	15.4	0.26
(P)	—	26.6	0.15
H	6.98	38.3	0.106
G	8.83	61.2	0.066
F	8.73	59.8	0.068
E	9.54	71.5	0.057
D	8.87	61.7	0.066
C	8.67	59.0	0.069
B	5.81	26.5	0.153
A	2.20	3.8	1.08. (Exit)

stream, it was seen that the air passed through without the formation of eddies.

The standard (but not standardized) mode of operations is as follows : 5 g. is weighed into a small receiver, and the air is turned on to the

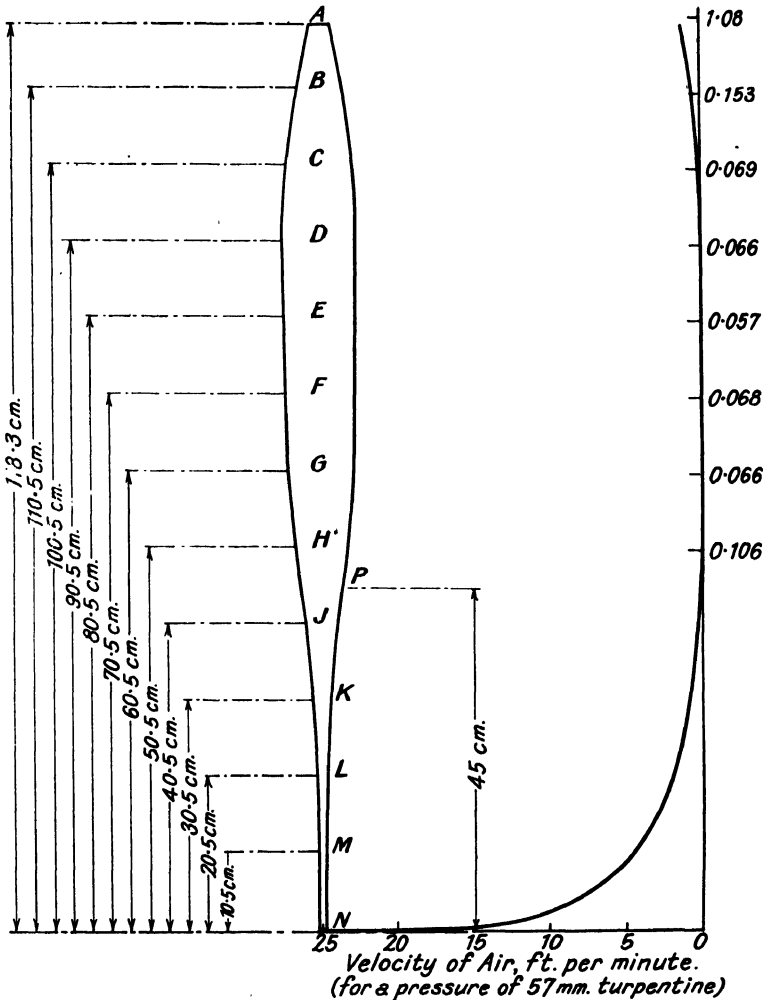


FIG. XI.5.—Flourometer, No. 11. Dimensions and Air Velocity.

apparatus and adjusted to the required pressure of 56 mm. of turpentine. The receiver is lowered into the flourometer, and emptied and withdrawn before the rising cloud of fine material can reach it. After 15 mins. the air current is stopped, the residue is collected from the angle tube at the base of the instrument, and weighed. This weight

is subtracted from the original 5 g. and the remainder is calculated as a percentage figure. Repeat determinations usually agree to within 0.5 per cent.

The only troublesome type of material is that of chalk, which balls together, sticks to the side of the vessel, and gives a continuous supply of fine material: such materials, however, are few. Provision should be made for the trapping of the fine material blown out of the apparatus.

A very careful and detailed investigation ¹⁹³ of the instrument, using standard Portland cement, ground slate, and clinker, led to the following conclusions:

Pressure. A change of 1 mm. turpentine led to a variation of 0.18 per cent. (average) of flour.

Time. About 85 per cent. of the flour is expelled in the first 2 mins. with the exception of chalk.

Temperature, Moisture in Air, Barometric Pressure, and Specific Gravity have little or no effect on the result.

Moisture in the Sample has little influence, but it is preferable that dry material should be used.

Size of the expelled grains. After the first few minutes, this does not vary much from 0.045 to 0.035 mm. (45–35 μ).

(The dimensions of an A.S.T.M. 200-mesh sieve are 74 μ .)

A water elutriator is described in B.S. 877: 1939 for Foamed Blast-furnace Slag.

The whole matter of elutriation has received wide consideration by Gonell ⁵⁰⁸, Heywood ⁵⁷⁵, and Dallavalle ⁵¹⁷.

Mechanical Tests of Bituminous Mixtures.

(*Note.*—The whole matter has received valuable constructive attention at the Public Works, Road and Transport Congress, held at London, 1933, under the auspices of the Society of Chemical Industry; and they have been greatly extended during recent years. See also ⁴²⁹.)

The importance of these tests has become established through the realization that the understanding of bituminous mixtures depends on something more than a knowledge of the properties of their components. It is being more and more clearly seen that tests carried out on ingredients are valuable mainly for restricting the nature of the constituent materials to that known to lead to good results; but how far these materials lose their identity in mixtures and their excellence in faulty workmanship, and how each contributes to the final result, was a mystery until the development of mechanical tests of the final mixtures.

It was realized by one of us that numerous mechanical tests had

been developed on the Continent of which this country had no counterpart. It was suggested to the British Standards Institution that these methods of tests should be standardized here for the benefit of those who wished to use them. This was soon amplified to a desire to consider the whole matter from the beginning, and a Committee started work in 1930. The work was again enlarged when the Ministry of Transport was asked to allow samples of asphalt and tarmacadam to be taken from certain roads for the purpose of testing the tests, and a joint Committee between the Institution and the Ministry was set up in 1932. The scope of work was still further extended by the examination of samples of surfacings to ascertain their rate of change under working conditions over relatively long periods. A large amount of work was done till the beginning of the War.

The laboratory work which was required to further the purposes of the Committee has been of permanent value, and has led to an increasingly clear understanding of the changes undergone, particularly of tar, in the cementing materials of the surfacings.

The Committee did not start in ignorance, already some work had been done in the Ministry's Road Laboratory at Harmondsworth; and certain firms of contractors had developed a number of tests in their own laboratories, and had interpreted results according to their own conditions. This latter work was put unreservedly at the disposal of the Committee, and was associated with experience of bituminous surfacings under traffic conditions; thus the development of the tests and the significance of their result were being fully co-ordinated. (See also ³⁷⁶.)

These tests, and some others, need be only shortly referred to here.

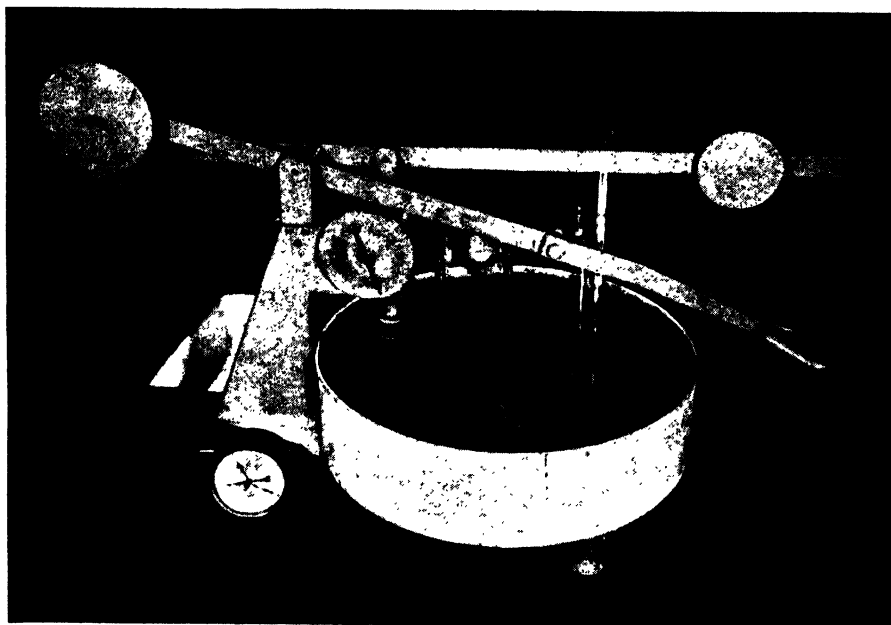
Pat Stain Number. The well-known Pat Test has been developed to give numerical measure of the 'richness' of a sample, by compressing a mixture between two wads of filter paper, and counting the number of papers that become stained. It can be used both for asphaltic and for tar mixtures.

Hardness Number. Samples of mastic are compressed to the density reached under traffic, allowed to age for seven days, and are then subjected to a big-scale penetration test.

The original Wilson mastic penetrometer has been improved, the basic change being the use of parallel levers, one being used to assist in the adjustment of the test lever and its release without jarring ¹⁸¹ (Fig. XI.6).

Deformation Test. This gives a measure of the plasticity of carpet, mastic mixtures, and of asphalt tiles. The weight is determined that is required to reduce the height of the sample, 2 in. high by 2 in. in diameter, by 20 hundredths of a centimetre.

Tensile Strength. Test pieces, moulded or cut from the solid, are tested in the form of briquettes of twice the size of standard Portland cement blocks, which can take mixtures containing 25 per cent. of $\frac{3}{4}$ -in. chippings. Experience has shown that the mixtures in which the proportion of binder gives the optimum tensile strength are those which also give the best results on the road. Indentation and compression tests give little information that is not obtained of the tensile measurements.



By the courtesy of Messrs. Highways Construction, Ltd.

FIG. XI.6.—Testing Machine for Mastic.

The study of tensile strength at constant load has led to such trustworthy understanding of these mixtures that the graphical solution of the design of dense tar surfacing for heavy traffic has been generally satisfactory ⁵⁴.

Stability (Extrusion) Tests. The Hubbard-Field machine ^{183, 377} indicated the stability of a mixture by the force necessary to extrude the test-piece through an orifice. This principle has been modified by measuring the force necessary to cause the commencement of extrusion ^{181, 437}.

This principle has been developed ¹⁸⁵ for use with mixtures containing coarse aggregate.

Stability (Shear) Test ¹⁸⁴ consists in compressing a block of mixture to the required density, and measuring the force necessary to shear it at a constant rate in a split steel cylinder. Much work has since been done in this country.

Impact Test. The Page machine, or close variants, are usually used.

In addition, *Bending, Permeability to Water* and its *Effects, Resistance to Attrition, Absorption to Shock, and Slipperiness*, have been investigated.

A *Friction Test*, employed for the rapid estimation of the stability of tar mixtures, consists in tamping the sample within a ring-shaped form and then attempting to polish it by rubbing—it may polish or it may disintegrate.

A *Sand-Blast Test* has been used, and has been abandoned.

The importance of mechanical testing of road surfaces has long been established and its methods realized; but when a sample is removed from the road for testing in a laboratory, there is always a doubt as to whether some cracking or lesser weakening has not taken place. In many cases this has not occurred, but testing *in situ* is the most desirable condition, and one that is scarcely developed. For this reason the following test is especially interesting.

Permeability to water of asphalt surfacings has been examined by S. C. Ells, of the Department of Transport, Ottawa, by means of a test applied directly to the road. In principle the test is carried out by means of an open-ended cylinder containing a known quantity of water, held in place against the surface of the road by the weight of the car transporting it, and provided with a window which enables the rate of leakage of the water into the road to be observed. There is often difficulty with the sealing, but this is allowed for ⁵⁷⁴.

Concrete and its Components. These are carefully regulated by specification (B.S. 882 : 1944 ; (War Emergency) 1020 : 1942 ; see especially ⁴⁵⁸).

Sand. The colour generated by the action of alkali or organic matter can be measured by a Lovibond comparator.

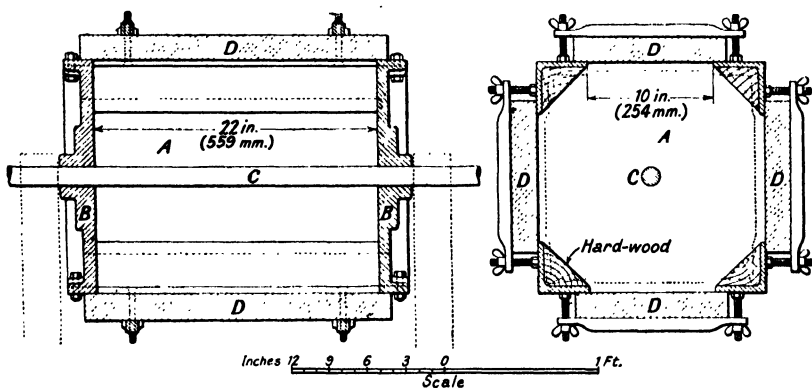
Water. In cases of doubt, running water should be sampled several times during the day; still water should be stirred thoroughly so as to include the sediment if this be in danger of being disturbed. Water, clean enough for drinking, is to be preferred.

In freshly made concrete, the proportion of water can be determined by admixture of calcium carbide, and the measurement of the increase of pressure caused by the acetylene generated. The figure obtained is then referred to a calibration curve ⁴⁷⁸.

Voids. The graduated jug method gives adequate results for ordinary purposes.

Slump Test. This consists on measuring the vertical subsidence of a conical mound of the material in a given time. It is affected by changes in the proportion and character of each of the several components of the mixture, so that results are comparable only amongst a series of mixtures where one component or characteristic is varied at a time. The test is of diminished significance, because vibration enables 'no-slump' mixture to be laid.

Other tests that are applied are for tensile and compressive strengths, bending and fracture of a beam, porosity, and resistance to frost, abrasion, attrition, and impact. The *compression* test, which is described in B.S. (War Emergency) 1020 : 1944, is widely used for testing concrete as a whole and also the quality of the cement used. In the



By the courtesy of the British Standards Institution.

FIG. XI.7.—The 'Elford' Machine for testing Flags, Bricks, etc. (B.S.S. 368 : 1936.)

latter case a standard mixture is made up into the usual cube, but only recently has the most sensitive operation, that of compaction of the mortar, been standardized. This is done by means of a motor-driven vibrator, working at 12,000 revolutions a minute with 0.2-in. eccentricity, and is described in B.S. 915 : 1940.

Test of Rate of Wear. The testing machine for this purpose (Fig. XI.7) is specified on B.S. 368 : 1936 for *Concrete Flags in Portland Cement*, but it is also useful for testing other materials such as bricks and timber. The machine is in the form of a rectangular box, with solid ends and open sides, the openings being closed by the samples under test. Into the container, thus formed, 1,000 hard steel or chilled cast-iron balls are introduced, each $\frac{1}{2}$ – $\frac{7}{8}$ in. diameter. The whole is then revolved for a particular number of times and at a specified rate. Examples of the appearance of test specimens after the test are seen in Fig. XI.8 ; and the amount of wear is shown

In America, where concrete roads are laid by the hundred miles, the resident engineer is furnished with a complete outfit for testing aggregates, cement, and concrete, including a beam-breaking machine. On completion of a contract, a pavement core drilling machine is sent over the road to drill out cores which are subsequently tested by crushing. This plant is expensive and not in general use in this country.

Tests of this kind, made after completion of the work, should, in any event, be treated as supplemental only to careful and constant supervision during the progress of the work.

Apart from the apparatus for slump test and moulds for compression cubes, it is unusual to supply the resident engineer with further testing apparatus, as it is generally more convenient to carry out tests at a central laboratory. Where, however, the work is extensive a set

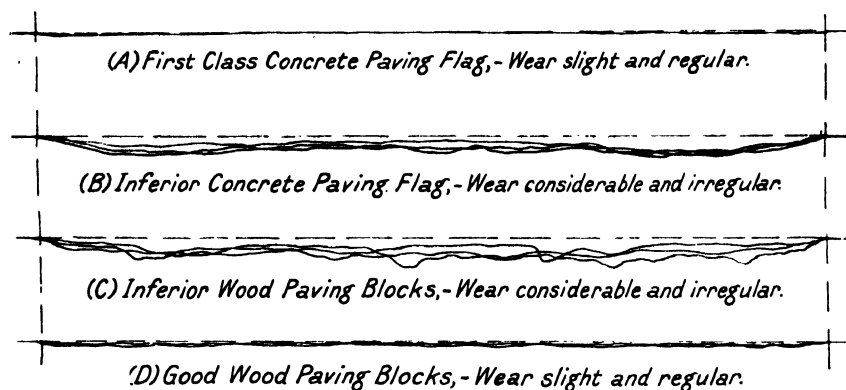


FIG. XI.9.—Transverse Contours of Samples after Testing in the 'Elford' Testing Machine (above).

of sieves for aggregate, with a bucket for volumetric measurements of material passing different meshes, is useful. The bucket should be circular with straight vertical sides, 10 in. in depth, so that every inch represents 10 per cent.

See also ¹⁷¹ for a good summary of requirements and methods ; also *Mobile Laboratories*, p. 346.

Much valuable information has been published by the Ministry of Transport.

Road Wear. The prime evidence of the excellence of a road is its behaviour under traffic for a minimum of 3 years. For rapid technical progress to wait so long is impractical, so that imitation, controlled and accelerated road tests have been devised. The first road machine was designed for the Road Board and erected at the National Physical Laboratory by Col. Crompton in 1912, in which the surfacing to be tested was laid in a circular track, over which weighted

wheels were run with a slow traversing motion. Three machines in all (the last was installed in 1936) have been in use at the Road Research Laboratory at Harmondsworth, and others have been worked abroad. On the whole there has been a disappointing lack of agreement between these tests and experience under real traffic, in spite of the imitation weather conditions which were installed. In America the opposite conclusion has been reached ⁵⁷⁶.

The healthy and unhealthy ageing of roads may be quick or slow, and rectification is the duty of the Surveyor. The methods for the observation, measurement, and record of such defects have been developed during a number of years.

The wear of asphalt and stone setts have been studied by means of a 30-mm. round steel plate, immovably embedded below the surface, and reached through a copper tube, packed with lead wool when not in use.

The top of the copper tube wears down with the surface, and the diminution of length down to the embedded plate is measured by a micrometer ⁵³⁰.

Wear in concrete surfacing can be followed by embedding in it a carefully tapered cone of coloured cement, and measuring its diameter.

The whole question of the behaviour of vehicles towards the road is extremely complex, and cannot be discussed here. Important work has been done in France and Italy ⁵²¹.

The *examination of the surface of a road* is of two kinds : (a) measuring and recording of irregularities such as ripples, and of depressions due to wear or faulty construction (see p. 32) ; and (b) changes in the surface.

Such changes produce slipperiness, disintegration, and unevennesses of many kinds. The whole matter has been well summarized ⁴³² and only indications can be given here of the methods employed, with some recommendations.

Measurements are usually made every 3 months or less. *Slipperiness* is measured by the skidding machine, described in Road Research Technical Papers Nos. 1 and 2 ; Road Research Bulletin No. 1 ; Road Board Report, 1938, p. 131. *Texture Print* (Road Research Bulletin No. 3) is taken much like an elementary printing machine—an inked roller is run over the surface of the road and paper is pressed on to the inked surface. *Roughness Index* is a numerical value obtained by filling the interstices between the ' high points ' of the surfacing with sand or finer material and dividing the quantity used by the total area of the areas so filled. General *disintegration* over a specified length of road is (fractionally) measured by the daily sweeping up and measuring of detritus from the edge of the road. *Pot-holes* : either

the area is measured periodically, or the date is noted when the base course becomes visible. *Surface dressings* : defective areas are measured. *Miscellaneous records* may usefully be made of the position of individual stones ; by means of photography ; the use of plaster casts ; rebound of a drop hammer, but this may damage the road.

Statistical records are invaluable in studying traffic movement and distribution. They may be taken by contact pads and electrical record. The wet-road clock (Road Research Report, 1937) records conditions by electrical conductivity. Surface temperature records can be valuable. A camera obscura greatly helps in the mapping of traffic.

APPENDIX I

ROAD ORGANIZATIONS, ETC.

THE WORSHIPFUL COMPANY OF PAVIORS, 130 Mount Street, Berkeley Square, W.1.

The beginnings of this City Company are unrecorded, but it is known to have been active in 1302, and that its first Ordinances were granted in 1479. The grant of Arms of the Company dates from the time of Elizabeth or earlier, but it was as late as 1929 or 1930 that they were corrected and registered at Heralds' College.

The Company has never possessed its own Hall. The privilege of livery was granted in 1900. The Company took a prominent part in 1928 to 1929 in establishing the Chair of Highway Engineering, at the University of London. A History of the Company has appeared in *The King's Highway* in June 1931 and onwards.

ASPHALT ROADS ASSOCIATION, 53 Victoria Street, S.W.1.

To promote the use of asphalt in road construction on the basis of experience and established principles ; to act as a centre of information and as a consultative body. It is not a trade combine.

Publications : *The King's Highway* (quarterly).

AUTOMOBILE ASSOCIATION, Fanum House, New Coventry Street, W.1.

The objects of the Association developed primarily for the benefit of motorists ; but regular reports on the condition of roads and the weather, and assistance in traffic control through patrols and temporary deviation signs are of advantage to road administration.

Publications : Handbook, maps, technical and advisory matter.

BRITISH CAST CONCRETE FEDERATION (*including the British Concrete Federation, Cast Concrete Products Association, Ltd., and the National Association of Cast Concrete Products Manufacturers ; the Scottish Precast Concrete Manufacturers' Association is affiliated*), 17 Amherst Road, W.13.

To uphold a standard of excellence in manufacture and to conduct research ; to treat with labour ; to organize large-scale production and distribution of concrete castings to Government requirements.

Publications : technical.

BRITISH RHEOLOGISTS' CLUB, Hon. Sec. Royal Aircraft Establishment, Farnborough, Hants.

To co-ordinate activities, to further appreciation of the subject, and in spreading information.

Publications : quarterly bulletin.

BRITISH ROAD FEDERATION, 4a Bloomsbury Square, W.C.1.

To promote and protect the interests of those concerned in the construction or in the use of roads ; to promote a constructive transport policy in the national interest.

Publications : Propaganda pamphlets, etc. ; *Monthly Bulletin of Road Information* ; *Basic Road Statistics*. Reports.

BRITISH ROAD TAR ASSOCIATION, 1 Grosvenor Place, S.W.1.

To promote and develop the use of British tar and tar products for road and other purposes, by propaganda, co-operative research, service, and practical experiment under traffic.

Publications : explanatory and technical matter ; *Monthly Bulletin*, etc., private to members.

BRITISH STANDARDS INSTITUTION (earlier, *British Engineering Standards Association*), 28 Victoria Street, S.W.1.

To co-ordinate the efforts of producers and manufacturers for the improvement, standardization, and simplification of engineering and industrial methods ; to increase efficiency by eliminating unnecessary varieties of patterns and sizes of articles for the same purpose ; to establish standards of quality and dimensions and to promote the adoption of British Standard Specifications.

Publications : British Standard Specifications ; *Standards Review* (quarterly).

CAST STONE AND CONCRETE FEDERATION (formerly the *Federation of Manufacturers of Artificial Stone*), Victory House, Leicester Square, W.C.2.

To promote the interests of the Federation, its members, and the trade ; and good relations with labour.

Publications : none.

CEMENT AND CONCRETE ASSOCIATION, 52 Grosvenor Gardens, S.W.1.

To extend and improve the use of cement and concrete.

Publications : many technical pamphlets.

(When the industry was re-organized in 1935, the British Portland Cement Association, Ltd., gave place to this new body. The former company together with the Associated Portland Cement Manufacturers, Ltd. both sell through the Cement Marketing Co., Ltd.)

CHARTERED SURVEYORS' INSTITUTE, 12 Great George Street, S.W.1.

To secure the advancement and to facilitate the acquisition of that knowledge which constitutes the profession of a surveyor ; to promote the general interests of the profession, and to maintain and extend its usefulness for the public advantage.

Publications : *Journal* (monthly ; to Members only) ; technical memoranda.

COUNTY SURVEYORS' SOCIETY, County Hall, Chichester, Sussex.

To consider problems arising out of County Administration, and to disseminate information relating thereto ; to act as a consultative body.

Publications : none.

FEDERATION OF COATED MACADAM INDUSTRIES, 37 Chester Square, S.W.1.

To promote the use of coated macadam, by maintaining high standards of quality and by dissemination of information.

Publications : none.

INSTITUTE OF QUARRYING, Salisbury Square House, E.C.4.

To promote and consolidate progress in the industry and profession ; to maintain professional standing by means of qualifying tests of candidates and supervision of members.

Publications : *The Quarry Managers' Journal* (monthly).

INSTITUTE OF TRANSPORT, 15 Savoy Street, W.C.2.

To promote, develop, and disseminate the knowledge of, the science and art of Transport in all its branches and appliances connected therewith.

Publications : *The Journal* (monthly) ; *The Institute Notes*, etc.

INSTITUTE OF WORKS AND HIGHWAY SUPERINTENDENTS, The Cottage, Edensor Road, W.4.

To create and maintain a high standard of efficiency in the profession by the discussion of principles and practice ; to establish a system of training and examination ; to promote improvements in the Law ; and to seek recognition of the Membership among Local Authorities.

Publications : Official Organ : *Highways, Bridges and Aerodromes*.

INSTITUTION OF CIVIL ENGINEERS, Great George Street, S.W.1.

To advance mechanical science, and more particularly to promote the acquisition of that species of knowledge which constitutes the profession of a Civil Engineer. A Road Engineering Division was established in 1939.

Publications : Minutes of Proceedings ; *Selected Engineering Papers* ; *Engineering Abstracts*.

INSTITUTION OF HIGHWAY ENGINEERS, Parliament Mansions, Abbey Orchard Street, S.W.1.

To promote progress in the practice of Highway Engineering and allied matters ; to develop the best interests of the profession ; to hold examinations ; to initiate and stimulate improvements in technique and in legal and administrative activities ; and to keep members informed on all matters affecting Highway Engineering.

Publications : *Journal*.

INSTITUTION OF MUNICIPAL ENGINEERS (till recently, Institute of Municipal and County Engineers), 84 Eccleston Square, S.W.1.

To promote the science and practice of engineering, surveying, and sanitation applied to roads, bridges, sewerage, and sewage disposal, drainage, water supply, town planning, and other works undertaken by Local Authorities ; to promote the professional education, status, and interests of engineers and surveyors of local authorities, and to hold examinations.

Publications : *Journal* (fortnightly) ; *Official Road Abstracts* as supplement.

NATIONAL HORSE ASSOCIATION OF GREAT BRITAIN, Chalmers House, 43 Russell Square, W.C.1.

To watch the condition of roads in the interests of the safety of horses, cattle, etc.

Publications : Reports.

NOISE ABATEMENT LEAGUE, 105 Gower Street, W.C.1.

To promote the cause of quiet and to prevent interference with the amenities of life by avoidable noise, through research, dissemination of information, and enforcement of the Law.

Publications : Magazine, *Quiet* ; leaflets.

PEDESTRIANS' ASSOCIATION, 180 Fleet Street, E.C.4.

To ensure the safety of the Public on the highways, and to promote and preserve the rights and the general amenities of all who use our roads on foot.

Publications : *Quarterly News Letter*, pamphlets, etc.

PERMANENT INTERNATIONAL ASSOCIATION OF ROAD CONGRESSES, L'Avenue d'Iéna, Paris.

Founded in 1908 to unite the interests of, and to foster cordial relations between, those interested in all problems affecting the roads and traffic of the world. It acts as the central organization of Congresses that are usually held ever four years. [In abeyance.]

Publications : *Bulletin* (every two months). Bibliographical Index ; *Dictionary of Road Terms in Six Languages* (interim printing for further correction).

ROAD EMULSION AND COLD BITUMINOUS ROADS ASSOCIATION, LTD., 66 Victoria Street, S.W.1.

To promote the progress of the industry, to protect the interests of the firms engaged in the industry, and to co-operate in the establishment of Standard Specifications and Tests.

Publications : none periodically. *Modern Road Emulsions*, 1939.

ROADS IMPROVEMENT ASSOCIATION (Incorporated), 180 Clapham Road, S.W.9.

To unite and represent all classes of road users in the common campaign to obtain adequate roads, bridges, and footways, attractive in character, and pleasant and safe for all purposes of travel.

Publications : various.

ROYAL AUTOMOBILE CLUB, Pall Mall, S.W.1.

The objects of the Club are primarily for the benefit of motorists ; but it is particularly interested, through its Highway Department, in the development of British roads and their equipment to accord with modern traffic requirements.

Publications : Handbook ; maps, pamphlets, etc.

ROYAL SOCIETY FOR THE PREVENTION OF ACCIDENTS, 52 Grosvenor Gardens, S.W.1.

[Roads.] To promote safety on the roads for all sections of users, by means of statistical analyses, warnings, and advice to individuals, Schools, and Authorities.

RUBBER ROADWAYS, LTD. (*under the auspices of The Rubber Growers' Association*), 19 Fenchurch Street, E.C.3.

To investigate and develop new uses for rubber, particularly in the direction of road paving.

Publications : pamphlets.

'SAFETY FIRST' LEAGUE : see ROYAL SOCIETY FOR THE PREVENTION OF ACCIDENTS.

SOCIETY OF CHEMICAL INDUSTRY, ROAD AND BUILDING MATERIALS GROUP, 56 Victoria Street, S.W.1.

To promote the scientific study of all materials, processes, and methods in the road and building industries, together with matters of allied interest.

Publications : *Journal ; Chemistry and Industry : Road Abstracts* as supplement.

STANDARDIZATION OF TAR PRODUCTS TESTS COMMITTEE, 166 Piccadilly, W.1.

To standardize the methods for testing tar and its constituents.

Publications : *Standard Methods for Testing Tar and its Products*.

APPENDIX II

LITERATURE TO BE CONSULTED

PERIODICALS

- Civil Engineering.* Weekly. Aldwych House, W.C.2.
Contractors' Record. Weekly. Norfolk Street, W.C.2.
Contract Journal. Weekly. 127 Temple Chambers, E.C.4.
Engineer, The. Weekly. 28 Essex Street, W.C.2.
Engineering. Weekly. 35 Bedford Street, W.C.2.
Highway Engineer and Local Government Surveyor. Monthly. 6 Thornton Park, Dalton-in-Furness.
Highways, Bridges, and Aerodromes. Weekly. Crescent House, Ashford, Middlesex.
Municipal Engineering. Weekly. 8 Breams Buildings, E.C.4.
Journal of Scientific Instruments. Monthly. Institute of Physics, 47 Belgrave Square, S.W.1.
Municipal Journal. Weekly. 3-4 Clements Inn, W.C.2.
Roads and Road Construction. Monthly. 66 Victoria Street, S.W.1. (Issues a valuable Year Book.)
Surveyor and Municipal and County Engineer. Weekly. 14 Bride Lane, W.C.4. (Issues an excellent yearly summary.)

The specialist journals of the quarry, cement, sand, etc., are not included in the above list.

Periodical Publications are issued by the following Institutions and other organizations, closely connected with road work :

Asphalt Roads Association—*The King's Highway.*

British Portland Cement Association.

Cement and Concrete Association Ltd.

Institute of Petroleum.

„ „ Quarrying.

„ „ Transport.

Institution of Civil Engineers.

„ „ Highway Engineers.

„ „ Municipal Engineers (till recently Institution of Municipal and County Engineers).

Permanent International Association of Road Congresses.

Shell-Mex & B.P. Ltd.

Society of Chemical Industry, Road and Building Materials Group.

BOOKS

(Other than those already mentioned)

British Roads. G. M. Boumphrey, 1939.

Street Traffic Flow. Henry Watson, 1933.

Death on the Roads. G. W. Wray, 1938.

Roadmakers' Library.

Basic Road Statistics. British Road Federation.

Road Abstracts. Road Research Laboratory and the Ministry of Transport.

Roads and Road Construction Year Book.

Road Research Laboratory : Various publications.

REPORTS

Road Research Board.

Ministry of Transport Advisory Committees.

London and Home Counties Advisory Committee.

Permanent International Association of Road Congresses.

World Petroleum Congress.

APPENDIX III

STANDARDIZATION

Standardization is invaluable for the sake of the simplicity and economy which result from its judicious employment. For its successful application it must be directive and must have a certain degree of permanence, although it must not exert an oppressive or restrictive influence on legitimate industrial progress. To attain this ideal the standards which are set up are based on the agreement of all interests concerned and have their full support ; and they are open to revision whenever unjustifiable limitations become apparent.

National organizations for the preparation of standard specifications now exist in every civilized country. The first of these organizations was the Engineering Standards Committee set up in this country in 1901, which developed into the British Engineering Standards Association incorporated in 1928 ; and this, in 1931, into the much larger British Standards Institution.

The extended organization now also embraces Chemistry and Building ; and has strengthened its relations with the Standards Associations of Australia and Canada, India, Palestine, and the local Committee of South Africa. By the mutual interchange of draft specifications, a great measure of Empire agreement is being achieved, and the British Standard Specifications are being adopted, so far as local conditions permit, throughout the Empire.

The British Standard Specifications, for the preparation of which this Institution is responsible, have proved to be of great value to producers, purchasers, and scientific workers in this country. They afford clearly defined bases for tendering and for guidance as to the best opinion on the particular matter controlled. In many instances they have been of value outside Great Britain and have done much to maintain British prestige abroad.

The British Standards Institution does not issue tentative standards (though some Tests may be 'tentative'), as it regards all of the British Standard Specifications as being tentative in the sense that they are always liable to revision, and the Committees of the Institution are kept standing so that they may undertake such revision as occasion may demand.

Standardization may be carried out primarily for the following purposes :

To establish standard sizes for articles in order to eliminate unnecessary products of manufacture by reducing their varieties and patterns, whereby considerable savings in manufacturing and distribution costs may result, and to secure interchangeability of articles or of their component parts.

To establish standards of quality and so to limit the range of production and achieve a sustained uniformity of quality and standard of performance.

To set up standard methods of test procedure (codes of Practice), so that operations may be conducted in exactly the same manner.

To establish standard nomenclature and definitions in order that the meanings of words, phrases, and symbols may be universally understood.

These factors are amongst the more important which, severally or collectively, are involved in the formation of a standard specification. (See also ²⁷⁸.)

A recent development is the issue of a British Standard Mark, for materials produced of a constant and recognized quality. Very stringent inspection is undertaken to ensure there is no falling off.

Attention should be drawn to the attitude of the Ministry of Transport towards standard specification. This is clearly given in Circulars 360 (Roads) *a* and *b*, showing that the B.S.I. specifications should be worked to *when they apply*: "In suitable cases a clause shall be included in contracts to secure that the British Engineering Standards Association" (as it was then) "specification, when one exists, shall apply in the case of materials for which it is not considered necessary to lay down a particular specification. When specifications of materials are included, these should be in accordance with the relevant specification of the British Engineering Standards Association." Thus, there is no trace of intention that *only* that which conforms to the B.S.I. specifications shall be admitted; so that the Engineer is free to try new materials and processes if in expert opinion (his own or that of an independent consultant) there are more chances of success than failure in the trial.

British Standard Specifications were given increased importance by a Circular addressed by the Ministry of Health ²¹⁸ to Local Authorities (excluding the L.C.C.) directing attention to Sec. 266 of the Local Government Act, 1933, which provides that the placing of contracts by Local Authorities shall be subject to Standing Orders to be adopted by each authority.

The draft Standing Orders prepared by the Ministry require that all contracts shall be based upon British Standard Specifications when appropriate Standard Specifications are available, and that there shall be no departure from such specifications except by approval of the Council or a committee to permit variations. (See also ⁵⁹³.)

Nationally, agreement upon the terms of a standard is not always easy to achieve, but international standardization is generally much more difficult of attainment owing to much wider differences in local conditions and industrial requirements, which often necessitate a whole nation, or nations, making concessions in its ideas and procedure if international agreement is to be secured. Yet this is often satisfactorily achieved.

An example of success in international standardization is found in the activities of the International Committee for the Standardization of Nomenclature and Tests, established by the Permanent International Association of Road Congresses (Paris) at the request of the Fifth International Road Congress held in Milan in 1926. This Committee, of road

engineers and others associated with roads, has achieved practically a universal measure of agreement in its *Technical Dictionary of Road Terms in Six Languages* ³⁵, and where, in a few instances, America has found it impossible to agree, a second-best result has been achieved by making absolutely clear the differences in meaning that attached to certain words. Unfortunately this was issued to the public in an unfinished state, and made a bad impression owing to lack of emphasis on the interim nature of the publication ; it was, actually, a summary of decisions, prepared for final consideration and improvement.

The *Glossary of Highway Engineering Terms*, B.S. 892 : 1940, is very closely founded on the English of the international committee's work.

APPENDIX IV

BRITISH STANDARD SPECIFICATIONS

- 12 : 1940. Ordinary Portland and Rapid-hardening Portland Cements. Amendment, 1942.
- 63 : 1939. Road stone and Chippings, Sizes of.
- 76 : 1943. Tar for Road Purposes (War Emergency Issue). Amendment, 1946.
- 144 : 1936. Coal Tar Creosote for the Preservation of Timber (Types A, A2 and B). War Emergency Revision, 1941.
- 146 : 1941. Portland-blastfurnace Cement not exceeding 65 per cent. Blastfurnace Slag. Amendment, 1942.
- 188 : 1937. Determination of Viscosity of Liquids in Absolute (C.G.S.) Units, Method for the. Amendment, 1940.
- 340 : 1936. Pre-cast Concrete Kerbs, Channels and Quadrants. Amendment, 1938.
- 347 : 1928. Asphalt Macadam (penetration method). Amendment, 1930.
- 348 : 1945. Compressed Natural Rock Asphalt.
- 350 : 1944. Conversion Factors and Tables.
- 368 : 1936. Pre-cast Concrete Flags in Portland Cement. Amendment, 1942.
- 405 : 1945. Expanded Metal (steel) for General Purposes.
- 410 : 1943. Test Sieves. Amendment, 1943.
- 433 : 1931. Cold Asphalt Macadam, Penetration (grouting and semi-grouting) Method, using Road Emulsion.
- 434 : 1935. Asphaltic Bitumen Road Emulsion for Penetration (grouting and semi-grouting) and Surface Dressing.
- 435 : 1931. Granite and Whinstone Kerbs, Channels, Quadrants, and Setts.
- 457 : 1932. Identification of Chemical Pipe Lines.
- 481 : 1933. Woven Wire and Perforated Plate Sieves and Screens for Industrial Purposes.
- 497 : 1945. Cast Manhole Covers, Road Gulley Gratings and Frames.
- 505 : 1939. Road Traffic Control (electric) Light Signals. Amendment, 1939.
- 510 : 1933. Single-coat Asphalt. Cold Process.
- 511 : 1933. Two-coat Asphalt. Cold Process.
- 566 : 1934. Internally-illuminated Yellow Diffusing Globes for Traffic Control Signals.

- 594 : 1945. Rolled Asphalt. Asphaltic Bitumen and Fluxed Lake Asphalt. Hot Process.
- 595 : 1935. Rolled Asphalt. Fluxed Natural Asphalt and Asphaltic Bitumen. Hot Process.
- 596 : 1945. Mastic Asphalt for Roads and Footways. Part 1 : Natural Rock Asphalt Aggregate. Part 2 : Limestone Aggregate.
- 597 : 1935. Mastic Asphalt Surfacing. Fluxed Natural Asphalt and Asphaltic Bitumen. Hot Process.
- 598 : 1940. Sampling and Examination of Bituminous Road Mixtures, Methods for the.
- 616 : 1938. Sampling of Coal Tar and its Products.
- 618 : 1935. Emulsions of Road Tar and of Road Tar-Asphaltic Bitumen Mixtures for Penetration (grouting and semi-grouting) and Surface Dressing.
- 706 : 1936. Sandstone Kerbs, Channels, Quadrants and Setts.
- 785 : 1938. Rolled Steel Bars and Hard Drawn Steel Wire for Concrete Reinforcement. Amendment, 1942.
- 802 : 1945. Tarmacadam and Tar Carpets (Granite, Limestone and Slag Aggregate).
- 812 : 1943. Sampling and Testing of Mineral Aggregates, Sands and Fillers, Methods for the. Amendment, 1946.
- 873 : 1939. Construction of Road Traffic Signs (cast metal) and Posts.
- 877 : 1939. Foamed Blastfurnace Slag for Concrete Aggregate.
- 882, 1198, 1199, 1200, 1201 : 1944. Concrete Aggregates and Building Sands.
- 892 : 1940. Highway Engineering Terms, Glossary of.
- 894 : 1940. Determination of the Flow and Drop Points of Fats and Allied Substances (Apparatus and Methods of Use.) (Ubbelohde Test.)
- 913 : 1940. Pressure Creosoting of Timber.
- 915 : 1940. High Alumina Cement.
- 1014 : 1942. Pigments for Colouring Cement, Magnesium Oxychloride and Concrete.
- 1020 : 1942. Concrete Road Slabs (War Emergency Issue). Amendment, 1942.
- 1047 : 1942. Air-cooled Blastfurnace Slag Coarse Aggregate (War Emergency Issue).
- 1144 : 1943. Cold Twisted Steel Bars for Concrete Reinforcement.
- 1152 : 1944. Rolled Asphalt (War Emergency Issue).
- 1165 : 1944. Clinker Aggregate for Plain Concrete, Composition and Soundness of.
- 1221 : 1945. Steel Fabric for Concrete Reinforcement.
- 1305 : 1946. Batch Type Concrete Mixers.
- A.R.P. 38. Traffic Paints (first revision).

CLASSIFICATION ACCORDING TO SUBJECT

<i>Aggregate</i>	<i>Conversion Factors and Tables</i>	<i>Quadrants</i>
63 | 882		340 | 706
812 | 1047	350	435 |
877 | 1165		
<i>Asphalt</i>	<i>Creosote</i>	<i>Setts</i>
347 | 595	144 | 913	435 | 706
348 | 596	<i>Emulsions, Bitumen</i>	
510 | 597	433 | 434	<i>Sieves</i>
511 | 598	<i>Emulsions, Tar</i>	410 | 481
594 | 1152	618	
<i>Cement</i>	<i>Flags</i>	<i>Tar and Tarmacadam</i>
12 | 915	368	76 | 618
146 | 1014		598 | 802
		616 |
<i>Channels</i>	<i>Glossary</i>	<i>Traffic Lights</i>
340 | 706	892	505 | 566
435 |		
<i>Concrete</i>	<i>Kerbs</i>	<i>Traffic Paints</i>
340 | 1020	340 | 706	A.R.P. 38
368 | 1035	435 |	
1014 |	<i>Manhole Covers</i>	<i>Traffic Signs</i>
	497	873
<i>Concrete Reinforcement</i>	<i>Pipe Lines, Chemical, Identification of</i>	<i>Viscometers</i>
405 | 1144		188 | 894
785 | 1221	457	

APPENDIX V

THE MILLILITRE

In this country and elsewhere the term 'millilitre' has replaced the 'cubic centimetre': this change is based on the re-definition of the kilogram.

Originally, the kilogram was defined as the mass of a volume of water of 1 cubic decimetre, at the temperature of maximum density; and from this the litre was derived as being the volume of 1 kilogram of water at the temperature of maximum density, and therefore the volume of 1 decimetre. Thus, the kilogram was the mass and the litre was the volume of 1 decimetre of water. The volume of the litre was therefore based on a unit of length, and the cubic centimetre was the systematic subdivision.

Owing to doubt being cast, at a later date, on the accuracy with which the standard kilogram had been determined and in order to avoid other sources of confusion, the whole matter was revised, and the litre was re-defined as being the volume occupied by a kilogram of water at the temperature of its maximum density³⁶⁰. Thus, this later measure of volume depends on mass and not on length, so that the subdivision is equally independent of length and the name 'cubic centimetre' officially disappears in favour of *millilitre*. In practice the c.c. has had to be retained in certain cases, but those organizations responsible for the scientific and technical development of road matters have been able to follow the new lead.

The conversion of the one into the other is effected by the following relation:

$$1 \text{ litre} = 1,000 \text{ millilitres} = 1,000.028 \text{ cubic centimetres.}$$

TYPICAL FORMS FOR USE BY LOCAL AUTHORITIES

Form No.....

DIVISIONAL SURVEYORS' REQUISITIONS FOR MATERIALS, HAULAGE, ETC.

DIVISION.....

[illegible]

Dated.....19.....

Signed.....

District Surveyor.

DAILY SHEET

COUNTY ROADS

	MOTOR LORRY	No.....	MAKER.....	Unladen Weight of Front Axle = T.....C.....Q.....	CONTRACTOR.....day of.....19.....
	STEAM WAGON	No.....	MAKER.....	Unladen Weight of Rear Axle = T.....C.....Q.....	

Journey No.	Place where Standing.	Place of Loading.	Place of Delivery.	Road No.	Works No.	Miles Covered.		Material Hauled.		Truck Number (when hauling from Station).	Actual Weight Carried in Tons.	State here if any Stoppage of Works amount of time lost and reason for same.
						Full.	Empty.	Description.				
1	2	3	4	5	6	7	8	9	10	11	12	
1												
2												
3												
4												
5												
6												
7												
8												
9												
10												
11												
12												

Allocation of Hours Worked

Road No. Works No. Hours.

Speedometer Readings :

Commence at

Finish at

Totals to be filled in at Headquarters.

Ton Mileage.....

Commencement of Day's Running Time.....a.m.

Vehicle

I hereby certify the above particulars to be correct

Termination

Time:
Hours

.....Driver.

Total Hours run

See Col. 12)

Examined *Foreman*.

At the conclusion of the Day's Work this Duplicate Sheet to be sent to the Foreman in charge. The Foreman will check and sign each sheet. The Foreman will forward the DUPLICATES to the Divisional Surveyor as required.

STAFF VEHICLES SUPPLIED BY STAFF

Weekly Return of Mileages and Amounts Claimed.

Motor Car—Reg. No. Make.....H.P..... Motor Cycle—Reg. No.....Make.....
 Authority to use on Council Service—No. Date.....19 Return for Week ending.....19 .

Date.	Route Covered (County Road Numbers).	Works, Gangs, etc., Visited.	Mileometer Readings. Start and Finish.	Mileage each Day.	Authorized Mileage Rate.	Amount Due. s. d.	Remarks.
Mon. . .							
Tues. .							
Wed. . .							
Thurs. .							
Fri. . .							
Sat. . .							
Totals							

I hereby certify the above particular and claim to be correct.....Member of Staff authorized to provide Vehicle.
 Countersigned.....Divisional Surveyor.

Form No.....

STAFF VEHICLES OWNED BY COUNCIL

Weekly Return of Mileages, Expenses, &c.

Motor Car—Reg. No.....Make.....H.P.....Motor Cycle—Reg. No.....Make.....
 Week ending.....19 .

Date.	Route (County Road Numbers).	Mileometer Readings. Start and Finish.	Mileage each Day.	Stores received :—			Particulars of Repairs and Sundry Disbursements.	Cost of Repairs, Petrol, Stores and Dis- bursements. £ s. d.	Member of Staff using Vehicle.	Remarks (includ- ing by whom repairs executed and source of Stores, etc.).
				Petrol. Galls.	Oil. Qrts.	Grease. Lbs.				
Mon. .										
Tues. .										
Wed. .										
Thurs. .										
Fri. . .										
Sat. . .										
Totals										

Certified.....Divisional Surveyor.

Form No.....

BITUMINOUS MATERIAL—DAILY REPORT

DATE.....19..... DEPOT.....

PLANT.....

TYPE OF WORK.....

No. of Men employed..... Man-hours worked.....

Mixing Plant

Hours working.

Hours standing.

Reason for standing.

Class of Material.	No. of Batches.	Total Weight.		REMARKS.
		Tons.	Cwts.	

GAUGING OF MIXTURE. *

No.	BITU-MEN.	STONE.	GRAVEL.	SAND.	FILLER.	Penetra- tion at°	REMARKS.
	%	%	%	%	%		
	%	%	%	%	%		

REMARKS.

Signed.....

Form No.....

Division.....

Gang No.....

BITUMINOUS SURFACING—DAILY RETURN

Date.....194.....

Road Number..... Name.....

Section of Road..... Works No..... Job No.....

Description of work.	Observations.

ROLLERS

Number..... Type..... Weight..... Owner.....

Stores Used.			Times of Work.		Actual time employed on Road, excluding meals, Repairs, Cleaning, Frost, etc. Hours.		Hours Travelling.	Hours Standing.
Coal or Oil Fuel. cwt.s.	Oil. qts.	Waste. lbs.	Commencing.	Finishing.	Rolling.	Scarifying.		

Kind of Material rolled.	Surface covered.		Area in Sup. yds.	Remarks.
	Length in yds.	Width in yds.		
Sub Crust				
Binder Coat				
Top Coat				
Surface Dressing				
Burning off				

Rolling Gang (including Chargeman)..... Watchmen.....

	Number of Men.	Commencing Time.	Finishing Time.	Total Hours.	Time Lost (Hours).	Reasons for Lost Time.
Sub Crust						
Binder Coat						
Top Coat						
Surface Dressing						
Burn'g Off						

Day-Haulage (Horse)—other than water.

Name of Hauler.	Number of			Description of Material.	Hours Worked.	Travelling Time. Hours.	Number of Journeys.	Average Length of Journey.
	Horses.	Carts.	Men.					

Water-Haulage.

Name of Hauler.	Mechanical or Horse.	Hours Worked.	Travelling Time. Hours.	Number of Journeys.	Average Length of Journey.	Average Load in gallons.	Where obtained.

Repairs, Tools, and Plant.

Name and Address of Firm or Tradesman.	Description of Repairs carried out and Materials supplied.	Remarks.

Signed.....Chargeman.

Signed.....Steam Roller Driver.

Checked and certified.....Foreman.

TEMPERATURE OF DRESSING	
8.0 a.m.....	Degrees, F.
11.0 a.m.....	Degrees, F.
3.0 p.m.....	Degrees, F.
Foreman's Initials.....	
THIS MUST BE COMPLETED DAILY	

Form No.....

.....DIVISION

Gang No.....

SURFACE DRESSING OF ROADS—DAILY RETURN BY CHARGEHAND

Date.....194.....

Dressing Material (liquid).....

Name of Road..... No.....

Position of Work.....

Number of Council's Men Engaged..... (including Chargemen)	Com-mencing Time.	Finish-ing Time.	Hours Worked.	Time Lost.			Reasons for Lost Time.
				From.	To.	Total Hours.	
With Boiler, etc.....men							
Cleaning Road and Gritting .....men							

Area of Road Dressed.			Condition of Surface : A. Previously Dressed. B. Not " C. Tar Macadam. " D. Concrete.	Dressing used :		Gritting used :			
Length.	Width.	Area.				Gravel.		Chippings.	
Yards.	Yards.	Sq. Yards.		Gallons.	Cwts.	Tons.	C. Yds.	Tons.	C. Yds.

Fuel received :

Coal.....cwt.s.

Supplied by

Coke..... "

Oil..... "

NOTE.—Delivery tickets for all materials must be signed by man receiving same and handed to Foreman.

MECHANICAL VEHICLES OR TEAM LABOUR EMPLOYED

Supplied by	Name
Number of Horses.....Carts.....Men.....	Number of Horses.....Carts.....Men.....
" " M. Vehicles.....	" " M. Vehicles.....
Commenced work at.....Finished at.....	Commenced work at.....Finished at.....
Hours worked.....	Hours worked.....
Hauling Tar	Hauling Tar
and Bitumen.....hours.	and Bitumen.....hours.
Hauling Grit.....hours.	Hauling Grit.....hours.
Sweeping Road.....hours.	Sweeping Road.....hours.
Gritting .....hours.	Gritting .....hours.

I hereby certify the above particulars to be correct.

(Signed).....

Charge hand.

Examined and certified.....

Foreman.

N.B.—At the Conclusion of each Day's Work, this Form to be sent to the Foreman. After checking and signing, the Foreman to send Sheet to the Divisional Surveyor, who shall cause the whole of the sheets for each week to be delivered to Headquarters by the following Tuesday morning.

Form No.....

Division.....

Gang No.....

MECHANICAL ROLLING—DAILY RETURN BY CHARGEHAND

Date.....194...

Name of County Road..... Road Number.....

Locality where Roller is working..... Works Number.....

Nature of work.	Observations.

Roller, Steam or Oil:..... Number..... Nominal Weight..... Owner.....

Materials Used.				Times Engaged.		Time Employed on Road Work.	Hours Traveling.	Hours Standing.
Coal or Coke. cwts.	Fuel Oil. gals.	Oil. pints.	Waste. lbs.	Commencing.	Finishing.			
						Hours. Rolling. Scarifying		

Material rolled :—	Gauge.	Quantity rolled.		Area covered.		Area in Sup. yds.
		Tons.	Cub. yds.	Length in yds.	Width in yds.	
1.						
2.						
3.						
4. Old Road Metal.....						
5. Blinding						
Scarifying done by Steam Roller						
" " " hand						

Total Number of Council's Men Employed with Roller (including Chargeman)..... Watchmen.....

	Number of Men.	Time of Commencing Work.	Time of Finishing Work.	Total Hours.	Time Lost and Reason for Same
1. Scarifying					
2. Spreading					
3. Barrowing materials & Loading Carts					
4. Blinding and Sweeping					

Day Cartage, Blinding Materials, Rehauling Stone, &c.

Name of Hauler.	Mechanical Vehicles.	Number of			Material.	Hours Worked.			Traveling Time Hours.	Number of Loads.	Average Length of Double Journey.
		Horses.	Carts.	Men.		From.	To.	Total.			
					Stone						
					Road Sweepings.						
					Blinding Gravel.						

Water.

Name of Hauler.	Haulage.		Hours Worked.			Travelling Time Hours.	Number of Loads.	Average Length of Double Journey.	Average Load in Gallons.	Where Obtained.
	Mechanical.	Horse.	From.	To.	Total.					

Repairs, Tools and Plant.

Name and Address of Firm or Tradesman.	Description of Repairs carried out and Materials supplied.	Remarks.

Signed....., Chargeman.

Signed....., Steam Roller Driver.

Checked by and Signed....., Foreman.

N.B.—At the conclusion of each day's work, this Form to be sent to the Foreman. After checking the Foreman will send original sheet to the Divisional Surveyor. The whole of the sheets for each week to be delivered to Headquarters by the following Tuesday Morning.

CONCRETE MIXER—DAILY RETURN

Date..... Vote No..... Job No.....

Concrete Mixer No..... Make..... Capacity.....

Working at.....

Concrete Mixer { at work.....hours.
standing..... „ Reason for standing.....Men employed { on mixer—Number..... Total hours.....
wheeling concrete—Number..... „ „

Fuel used.....Galls. used.....

Water used..... How supplied.....

MATERIALS USED :—

Broken stone.....cubic yards.

Gravel..... „ „

Ballast..... „ „

Sand..... „ „

Cement (ordinary)..... Tons (or Bags)

„ (rapid hardening)..... „ („ „)

Output :—

Mixed concrete.....cubic yards.

Concrete used in.....

.....

Slump Test (at intervals).....

.....

Water used per cubic yard of concrete.....

Weather and temperatures.....

.....

REMARKS.....

.....

Signed.....

Foreman.

Countersigned.....

Divisional Surveyor.

WEEKLY PROGRESS REPORT

No. Week ending 19.....
 Contract.....
 Vote No. Job No.
 Date specified for completion.....
 „ work commenced.....days.
 Time lost during week.....days.
 Time lost since commencement.....days.

Contractor
 Contractor's Agent or Foreman.....

PROGRESS OF WORK.

Men Employed (average).	No.	Machines and Plant.	No.	Description of Work.	Unit.	Quantity in Bill.	Approximate amount executed during Week.	Total approximate amount executed to Date.	Remarks.
Foremen		Pneumatic Drills		Removal of Trees	No.				
Gangers		Mechanical Navvies		Removal of Hedges and Fences	Yds. lin.				
Bricklayers		Concrete Mixers		Excavation	Yds. cube				
Paviors		Mechanical Rammers		Filling	Do.				
Carpenters		Locos.		Carriageways—					
Pipe Layers		Rollers (8 tons and over)		Clinker formation	Yds. sup.				
Platelayers		Rollers (under 8 tons)		Hardcore Foundation	Do.				
Joiners (Iron Pipe)				Concrete	Do.				
Fitters				Asphalt	Do.				
Blacksmiths				Tar Macadam	Do.				
Steel Benders and Fitters				Wood Paving	Do.				
Tradesmen's Labourers				Sett Paving	Do.				
General				Kerbing	Ft. lin.				
Do. (working in Water)				Carriageway Crossings	No.				
Concretors				Footways—					
Timbermen				Clinker	Yds. sup.				
Drivers (Concrete Mixers)				Artificial Stone Paving	Do.				
Do. (Mechanical Navvies)				Concrete in situ Paving	Do.				
Do. Loco.				Gravel	Do.				
Flagmen				Tar Paving	Do.				
Boys (14-21 years)				Ditches Excavated	Yds. lin.				
Watchmen				Sewers—					
Miscellaneous				9 ins. to 15 ins.	Do.				
				18 ins. to 21 ins.	Do.				
				24 ins. to 30 ins.	Do.				
				Culverts (over 30 ins.)	Do.				
				Manholes on Sewers	No.				
				Gullies and Connections	Do.				
				Reinforced Concrete Structures	Yds. cube				
				Refuges					
				Street Lamps					
Total									

Dates of entry upon private
 properties :—

REMARKS :—

Resident Engineer
 or Foreman in charge

[illegible]

Note.—This Form is intended to be used for checking *Unit Costs* during the course of construction. This is often a matter of considerable difficulty, principally for the reason that the quantity of work executed and the total cost at the time of measurement include incomplete units. The most effective method of reducing this difficulty is to limit the scope of each unit so far as practicable, e.g. 'kerb laid on concrete' might be divided into say four units: (a) kerb delivered; (b) excavation; (c) concrete, and (d) laying kerb on concrete. An alternative, where a multiplication of units is deemed to be inadvisable, is to include, in the monthly statement, completed units only and deduct from the expenditure in respect of each unit the estimated cost of unused materials and incomplete work. On extensive works it is sometimes convenient to treat all materials delivered as 'stock' and charge to the units as used. It may in some cases be considered necessary to limit unit costing to the more important items of work.

APPENDIX VII

TYPICAL FORMS FOR USE BY CONTRACTORS

LABEL

To be attached to all
samples forwarded to the
Central Laboratories.

(Two sides)

Sample No.
District
Plant
Material
Date Laid
Road
Position on Road
 (Important)
Thickness
Foundation
Condition of Base
Pen : of A.C.

ORIGIN OF MATERIAL USED

Filler
Sand
.....
.....
Stone
.....
.....
Flux

Weather

REMARKS

BOX WEIGHTS

A.C. { $\left. \begin{array}{l} \text{Epuré} \\ \text{Residual} \\ \text{Oil} \\ \text{Lakephalt} \end{array} \right\} \begin{array}{l} \% \\ \% \\ \% \\ \% \end{array} \right\} \dots \text{lbs.} \dots \% \\$
Filler
Sand
Stone

TOTAL lbs.

Residual
Tank, Car or Scammell No.
Plant Penetration
Suppliers' do.
Date Delivered

DEPOT DAILY REPORT

No.....

Depot.....

Contract..... **Date.....**

Material despatched to.....Distance.....

Number of carts employed **Number of journeys**.....

„ T.C. vehicles employed.....

Type of Plant..... Type of Loco.....

Plant Running, hours..... Plant Mixing, hours.....

Weather Conditions.....

Delays.....

Manufacturing.	No. of Mixings.	Weight of Mixings.	Tonnage.
Binder . . .			
Carpet . . .			
Total .			

Specification No.....

Sand Mixture

SAMPLES.

Material.	Sample No.	Hour of Despatch.
-----------	------------	-------------------

Fuel and Materials used.	Plant.	Boiler.	Loco.	Manufacturing.	Total.
Electricity					
Coal					
Coke					
Paraffin					
Filler					
Bitumen					
Flux					

Labour and Duties.	No.	Average Hours.	REMARKS.
--------------------	-----	----------------	----------

Signed

ROAD REPORT

Date.....19

Contract.....

Depot.....

Road

Identification Points :

Right

LABOUR EMPLOYED :

Left

Foreman Spreader
Spreader
Labourers { Unloader
Forker
Punner
Preparation

Material Laid.	Binder.	Carpet.
Specified thickness .		
Tonnage received .		
Measurements . .		
Area		
Supering		

Temperature of Materials received on Road { **Maximum**.....
Minimum.....

Determined Thickness of Carpet

Identification Point.	Crown.	Left Haunch.	Right Haunch.
1. 1000	1000	1000	1000
2. 1000	1000	1000	1000
3. 1000	1000	1000	1000
4. 1000	1000	1000	1000
5. 1000	1000	1000	1000
6. 1000	1000	1000	1000
7. 1000	1000	1000	1000
8. 1000	1000	1000	1000
9. 1000	1000	1000	1000
10. 1000	1000	1000	1000
11. 1000	1000	1000	1000
12. 1000	1000	1000	1000
13. 1000	1000	1000	1000
14. 1000	1000	1000	1000
15. 1000	1000	1000	1000
16. 1000	1000	1000	1000
17. 1000	1000	1000	1000
18. 1000	1000	1000	1000
19. 1000	1000	1000	1000
20. 1000	1000	1000	1000
21. 1000	1000	1000	1000
22. 1000	1000	1000	1000
23. 1000	1000	1000	1000
24. 1000	1000	1000	1000
25. 1000	1000	1000	1000
26. 1000	1000	1000	1000
27. 1000	1000	1000	1000
28. 1000	1000	1000	1000
29. 1000	1000	1000	1000
30. 1000	1000	1000	1000
31. 1000	1000	1000	1000
32. 1000	1000	1000	1000
33. 1000	1000	1000	1000
34. 1000	1000	1000	1000
35. 1000	1000	1000	1000
36. 1000	1000	1000	1000
37. 1000	1000	1000	1000
38. 1000	1000	1000	1000
39. 1000	1000	1000	1000
40. 1000	1000	1000	1000
41. 1000	1000	1000	1000
42. 1000	1000	1000	1000
43. 1000	1000	1000	1000
44. 1000	1000	1000	1000
45. 1000	1000	1000	1000
46. 1000	1000	1000	1000
47. 1000	1000	1000	1000
48. 1000	1000	1000	1000
49. 1000	1000	1000	1000
50. 1000	1000	1000	1000
51. 1000	1000	1000	1000
52. 1000	1000	1000	1000
53. 1000	1000	1000	1000
54. 1000	1000	1000	1000
55. 1000	1000	1000	1000
56. 1000	1000	1000	1000
57. 1000	1000	1000	1000
58. 1000	1000	1000	1000
59. 1000	1000	1000	1000
60. 1000	1000	1000	1000
61. 1000	1000	1000	1000
62. 1000	1000	1000	1000
63. 1000	1000	1000	1000
64. 1000	1000	1000	1000
65. 1000	1000	1000	1000
66. 1000	1000	1000	1000
67. 1000	1000	1000	1000
68. 1000	1000	1000	1000
69. 1000	1000	1000	1000
70. 1000	1000	1000	1000
71. 1000	1000	1000	1000
72. 1000	1000	1000	1000
73. 1000	1000	1000	1000
74. 1000	1000	1000	1000
75. 1000	1000	1000	1000
76. 1000	1000	1000	1000
77. 1000	1000	1000	1000
78. 1000	1000	1000	1000
79. 1000	1000	1000	1000
80. 1000	1000	1000	1000
81. 1000	1000	1000	1000
82. 1000	1000	1000	1000
83. 1000	1000	1000	1000
84. 1000	1000	1000	1000
85. 1000	1000	1000	1000
86. 1000	1000	1000	1000
87. 1000	1000	1000	1000
88. 1000	1000	1000	1000
89. 1000	1000	1000	1000
90. 1000	1000	1000	1000
91. 1000	1000	1000	1000
92. 1000	1000	1000	1000
93. 1000	1000	1000	1000
94. 1000	1000	1000	1000
95. 1000	1000	1000	1000
96. 1000	1000	1000	1000
97. 1000	1000	1000	1000
98. 1000	1000	1000	1000
99. 1000	1000	1000	1000
100. 1000	1000	1000	1000

Commenced Work.....

Finished Work.....

Time first load received.....

Time last load received.....

Weight of roller—Nominal.....

Type of roller.....

Actual.....

Remarks

Condition of Road Surface.....

Weather Conditions.....

Signed

GRANITED MASTIC—MANUFACTURING AND LAYING REPORT

Contract.....

Date.....19

Road.....

PLANT EMPLOYED

Plant running .....hours	Portable Engines	H.P.
Weather conditions	Tractors	H.P.
Total weight of charges in boilers.....	Boiler No. 1.	Tons Nominal Capacity
Actual Tonnage laid	" 2.	" " "
Area laid	" 3.	" " "
Supering	" 4.	" " "
Specified Thickness		

MANUFACTURING.	BOILER No. 1. Weights of—		BOILER No. 2. Weights of—		BOILER No. 3. Weights of—		BOILER No. 4. Weights of—	
	First Charge.	Second Charge.	First Charge.	Second Charge.	First Charge.	Second Charge.	First Charge.	Second Charge.
Bottom Coat . . .								
Mastic								
Total								
Temperatures . .								

FUEL & MATERIALS USED.	LOCOS.	SAND DRIERS.	BOILERS.	TOTAL.	SAMPLES.		
					Materials.	Sample No.	Time Despatched.
Coal							
Coke							
Paraffin							
Bitumen							
Chippings or Grit							
Mastic							
Sand							

LABOUR & DUTIES.	NO.	AVERAGE HOURS.	SPECIFICATION
DAY			DELAY, REMARKS, Etc.
NIGHT			
			SIGNED.....

APPENDIX VIII

TYPICAL FORMS FOR USE BY ROAD LABORATORIES

BITUMINOUS BINDER LABORATORY ANALYSIS CARD TAR, PITCH AND BITUMEN

<i>Received</i>	<i>Reported</i>	<i>Reference</i>	<i>No.</i>
Penetration @ 25° C.			
Ductility @ 25° C.			
Softening Point			
Viscosity (Engler) @ 200° C.			
Loss on heating (5 hrs. @ 163° C.)			
Appearance after heating			
TESTS AFTER HEATING :			
Penetration @ 25° C.			
Ductility @ 25° C.			
Softening Point			

<i>SAMPLE of</i>	
<i>Manufactured by</i>	
<i>Sent from</i>	
<i>Date</i> <i>ex ship</i>	
<i>Identification Marks</i>	
<i>CONTRACT</i>	
<i>Name of Plant</i>	
<i>REMARKS</i>	
.....	
.....	

LABORATORY ANALYSIS CARD (Two sides)

PAVEMENT & MINERAL AGGREGATE

<i>Received</i>	<i>Reported</i>	<i>Lab. No.</i>
Sp. Gr. Found Theor. Voids % Remarks.		SAMPLE of ex taken at Depot Sample No. CONTRACT Road Depot Date.....Time REMARKS

Wt. Pavement After extraction Sol. Binder	Tested by Checked by
---	-------------------------------------

Wt. Aggregate.....			Tested by :—		Checked by :—	
SIEVES.	WEIGHT.	DIFF.	%			
			DIRECT.	CUMU- LATIVE.	RATD.	COMPLETE B.
200						
100						
72						
52						
36						
25						
14						
8						
7						
1"						
3"						
1 1/2"						
1"						
1"						
1"						
1"						
Total						

PENETRATION @ 25° C. (after cooling @ 25° C. for 1 hour), under load of 100 kg. per sq. cm. applied through steel rod 1/4" dia. sq. end,				
Duration	1 min.	5 mins.	15 mins.	30 mins.
Penetration				

Tested by

LABORATORY REPORT (ROUTINE) ON ASPHALTIC BITUMEN

Date received.....

To..... *Date reported*.....

Lab. Sample No.

Depot Sample No.

Barrel Marks

Penetration @ 25° C.

Ductility @ 25° C.

Softening Point

Softens :

Melts :

Viscosity....., at.....° C.

Loss on Heating (5 hours @ 163° C.)

Appearance after Heating

TESTS AFTER HEATING

Penetration @ 25° C.

Ductility @ 25° C.

Softening Point, ° C.

REMARKS :

Lab. No.....

LABORATORY REPORT ON TAR

Analysis of a sample of Tar received from.....19.....

Description19.....

Taken.....19.....

Properties.	Specification for 70 secs. Viscosity.	Analysis.	Specification for 120 secs. Viscosity.	Analysis.
Water	Max. 0.5% by weight	.....	Max. 0.5% by weight	.....
Distillate.				
a. Oils below 200° C.	Max. 1.0% by weight	.....	Max. 1.0% by weight	.....
b. Oils between 200° C. and 270° C.	6.0%–13.0% by weight	.....	4.0%–11.0% by weight	.....
c. Oils between 270° C. and 300° C.	3.0%–9.0% by weight	.....	3.0%–8.0% by weight	.....
b + c.	Max. 20.0% by weight	.....	Max. 17.0% by weight	.....
Phenols	Max. 3.5% by volume	.....	Max. 3.0% by volume	.....
Naphthalene	Max. 4.5% by weight	.....	Max. 4.0% by weight	.....
Matter insoluble in toluene	Max. 23.0% by weight	.....	Max. 24% by weight	.....
Specific Gravity	Min. 1.110. Max. 1.250 at 15.5° C.	.....	Min. 1.120. Max. 1.260 at 15.5° C.	.....
Softening point of residue (R. and B.)	Max. 52.0° C.	.....	Max. 52.0° C.	.....
Viscosity	63–77 secs. at 30° C. B.R.T.A.	.....	108–132 secs. at 30° C. B.R.T.A.	.....
	31.4° C.–32.5° C. E.V.T.	.....	34.4° C.–35.5° C. E.V.T.	.....

Remarks :

Date.....19.....

Signed

LABORATORY REPORT ON ASPHALTIC BITUMEN AND TRINIDAD ASPHALT, FLUXES, ETC.

Test No. :

Material

Received : date
from

Density at 15.5° C.

Viscosity.....
at.....° C.

Soluble in.....%

FLUXING VALUE :

% Epuré } Pen. @
% Flux } 25° C.

Softening Point (R. & B.) ° C.

Fixed Carbon %

Free Carbon %

PENETRATION GMS. :

@ 15.5° C. (60° F.) (5 secs.)

@ 25° C. (77° F.) ,,

@ 29.5° C. (85° F.) ,,

@ 38° C. (100° F.) ,,

Mineral Ash, % of Bit.

% of Epuré

% of Flux

Closed Flash Point ° C.

Open Flash Point ° C.

Fire Point ° C.

LOSS ON HEATING for :

5 hrs. @ 163° C. (325° F.)

Further 5 hours

Further 5 hours.

TOTAL LOSS.

5 hrs. @ 163° C. (325° F.)

Further 7 hours 171° C. (340° F.)

Further 7 hours 204.5° C. (400° F.)

TOTAL LOSS.

Penetration, after heating

% of original penetration

Character of Residue

DUCTILITY IN CMS. :

@ 15.5° C. (60° F.)

@ 25° C. (77° F.)

@ 29.5° C. (85° F.)

@ 38° C. (100° F.)

REMARKS

Copies to :—
The County Surveyor,
.....

COUNTY ROADS LABORATORY

MINERAL AGGREGATE, SAND AND FILLER ANALYSIS

Lab. No.

Plant or Division Truck or Lorry No. Date Delivered
Road No. Works No. Map Ref. Date Sampled
Type of Material Specification Date Recd. in Lab.
Origin Supplier

SIEVE ANALYSIS.

Individual Percentages
Cumulative

Passing B.S. Sieves.
Retained

Specification min.
max.

Density (lbs./cb. ft.)	Apparent S.G.	Real S.G.	Spec.
Voids	Water Absorption	Organic Impurities	max.
Particle Shape	Surface Texture	Flour Content	
Loss on Ignition	Solubility in HCl	Silt Content	
General Trade Name		Flakiness Index	
Petrological Name and Description		Elongation Index	
		Roundness Index	

Date

Signed

REPORT OF ANALYSIS ON ASPHALT SURFACING

Date Received..... Date Reported

CONTRACT.....

DEPOT..... ROAD.....

Material.	Laboratory Sample No.	Depot Sample No.	Date Manufactured.	Specification No.
Sample Number				
BITUMEN %				
AGGREGATE : % passing	200			
% "	100			
% "	72			
% "	52			
% "	36			
% "	25			
% "	18			
% "	14			
% "	10			
% "	7			
% "	1 1/8 "			
% "	3/16 "			
% "	1/4 "			
% "	3/8 "			
% "	1/2 "			
% "	3/4 "			
% "	1 "			
% "	1 1/2 "			
% "	2 "			
% "	3 "			
Total				
FLOUR, %				
% Sol. in Dilute Hydrochloric Acid				
SPECIFIC GRAVITY				
Found				
Theoretical				
VOIDS %				
PENETRATION of BITUMEN				

REMARKS :

(See B.S. 598 and 940 for suggested Certificate of Routine Analysis.)

RESULTS OF PETROLOGICAL EXAMINATION

NAME

LOCALITY

SUBMITTED BY

SAMPLE No. DATE

1. AGE
2. STRATIGRAPHICAL HORIZON
3. TYPE OF DEPOSIT
4. DESIGNATION

LITHOLOGY

- | | |
|---------------------------------|-----------------------|
| 5. COLOUR (Fresh) | (Weathered Surface) |
| 6. STRUCTURE | 9. TEXTURE |
| 7. BEDDING | 10. LAMINATION |
| 8. CLEAVAGE | 11. JOINTING |
| 12. VISIBLE ORGANISMS (fossils) | OR ORGANIC STRUCTURES |
| 13. SPECIAL CHARACTERISTICS | |

MICROSCOPY

14. COMPOSITION
15. MICRO-STRUCTURE
16. MICRO-ORGANISMS
17. AVERAGE PARTICLE SIZE
18. PARTICLE SHAPE
19. ACCESSORY MINERAL SUITE

20. SOLUBLE BITUMEN CONTENT

CHECK

21. GRADING :—SIEVE TEST (B.S. Sieves).

Passing 300 mesh
Passing 240 mesh
Passing 200 mesh
Passing 100 mesh
Passing 85 mesh
Passing 52 mesh
Passing 36 mesh
Passing 25 mesh
Passing 18 mesh
Passing 8 mesh
Passing $\frac{1}{2}$ " mesh
Passing $\frac{3}{8}$ " mesh
Passing $\frac{1}{4}$ " mesh
Passing $\frac{1}{8}$ " mesh
Passing $\frac{1}{16}$ " mesh
Passing $\frac{1}{32}$ " mesh
Passing $\frac{1}{64}$ " mesh
Passing $\frac{1}{128}$ " mesh
Passing $\frac{1}{256}$ " mesh

COUNTY ROADS LABORATORY

Concrete --- Wet Analysis

Date of Sampling Analysis19..... Division.....

Supplies of Aggregate Road Number.....

Works Number.....

	Sample 1.	Sample 2.	Average.	Specification.
Fine Aggregate				
Coarse Aggregate				
Cement				
Water				
Total				
Aggregate/Cement Ratio				
Water/Cement Ratio				
Range of Sizes				
Retained				
Fineness Modulus				
Silt Content				
Organic Impurities				
Slump				
Cement used				
Test Number				
Remarks				

Tested by.....

Date.....19.....

Signature

REPORT ON TARMACADAM SURFACING

The following is an example of the relation between the reports on the laying of a surfacing, the laboratory check on the progress of the work, and the final questionnaire and report on the work 4 years later.

PRODUCTS DEPARTMENT

TARMACADAM AND CARPET PREPARATION AND LAYING

Report No. 21

Chemical Dept. Analysis Report No. 16

Date 30th October 1942

Council or Contractor *Blankford County Council.*

Location of Plant *Blankford.*

MIXING

Type of Carpet *Coarse $\frac{3}{4}$ " Granite.*

Type and Grade of Binder *Type 'C' tar. E.V.T. 38° C.*

Nature of Coarse Aggregate *Granite.*

Nature of Fine Aggregate *Sand.*

Nature of Filler *Limestone.*

Specification : Coarse Aggregate $\frac{3}{4}$ " 75 Temp. Stone 150 ° F.

Fine Aggregate $\frac{1}{4}$ "-200 mesh 20 Binder 170 ° F.

Filler (200 mesh) $\frac{5}{100}$

Binder 5.5 %

How Sampled *increment samples from a lorry.*

REMARKS ON MIXING : *Low temperature mixing plant with pre-drying unit and batch heating. Mixed 30 cwt. double paddle.*

LAYING

Weather *Fine, cool.*

Location of Road * *A.007 at Blankford* (See plan overleaf)

Approximate area to be treated *4,500 yards.*

Nature of base *old Surface dressing.*

Pretreatment (if any) *partly burnt off.*

Approximate time between mixing and laying *one hour.*

Temperature of mix at time of laying *140° F.*

Consolidated thickness *1 $\frac{1}{2}$ "* Area per ton *15 yards.*

Weight of roller *10 tons.*

REMARKS ON LAYING : *The work was being carried out effectively but very slowly. The first portion of each load was too cool for complete consolidation by the time the remainder of the load was spread. The effect was shown by the uneven texture of the carpet after laying. It is expected that the heavy traffic on the road will eliminate this variable texture.*

Signature.....

* *This had gradients of up to 1 in 6 and a specially rugous surface is required.*

OPEN CARPET LAID AT BLANKFORD

OCTOBER AND NOVEMBER, 1942

	Speci- fication.	OCTOBER.					NOVEMBER.				
		27	28	28	28	30	2	3	6	9	20
Moisture, %		0.3	0.4	0.5	0.3	0.2	0.3	0.2	0.2	0.2	0.2
Soluble Tar, %		4.55	4.93	4.7	4.37	4.35	4.62	4.29	4.24	4.72	4.54
E.V.T. of recovered tar, °C. . . .		44.4	43	46	45	43.3	45.7	47	47.3	46	41.7
Approximate percentage of original tar (calculated allowing for oil loss and free carbon)		5.49	5.83	5.76	5.37	5.25	5.65	5.3	5.27	5.77	5.58
Aggregate Composition :											
Stone, 1"- $\frac{1}{4}$ "	75	73	73	80	79	79	79	77	80	75	75
Sand $\frac{1}{8}$ "-200 mesh	20	24	22.5	15.5	17.5	17	17.5	19.5	16	20	20
Filler, passing 200 mesh	5	3	4.5	4.5	3.5	4	3.5	3.5	4	5	5
Grading :											
Percentage passing 1"		100	100	100	100	100	100	100	100	100	100
" " 3"		97	92	96	96	94	95	95	96	97	95
" " 1"		52	59	51	47	48	48	48	49	48	51
" " $\frac{1}{2}$ "		35	44	37	28	32	32	31	32	35	33
" " $\frac{3}{8}$ "		33	36	29	26	29	30	28	30	33	32
" " $\frac{1}{4}$ "		27	27	20	21	21	21	23	20	25	25
" " $\frac{1}{8}$ "		21	20	14	16	15	13	17	12	19	20
" " 18 mesh		18	17	12	14	13	11	16	11	16	18
" " 25 "		10	9	8	9	9	7	9	7	11	10
" " 52 "		5	6	6	5	6	5	5	5	7	7
" " 85 "		3	4.5	4.5	3.5	4	3.5	3.5	4	5	5
" " 200 "											

CHEMICAL DEPARTMENT,

9th August, 1946.

RESULT OF ANALYSIS

The following results have been obtained by the examination of the Sample of $\frac{3}{4}$ " Granite Carpet.

Marked Open Carpet laid at Blankford, A.007 on October and November, 1942.

Received

The material was required to give a more rugous surface than that usually obtained with a standard carpet as it was laid on a steep hill. This result was achieved by reducing the proportions of the smaller sizes of stone in the coarse aggregate. Several samples of the material supplied were analysed and the results obtained are given on the attached sheet.

COMMENT

The binder content in all samples conformed to the specification and the viscosity of the recovered binder indicates that mixing conditions were satisfactory. The grading clearly shows that the smaller sizes of stone in the coarse aggregate were kept to the minimum, and the fine aggregate though variable conforms to the normal limits for this type of material. The filler content is somewhat low in the earlier samples but as the results show was increased to a suitable amount.

PRODUCTS DEPARTMENT
INSPECTION OF CARPETS

Report No. 28.

Mixing & Laying
Report No. 21.

Date 5th May, 1946.

Council *Blankford.*

Location of Road *Blankford, A.007.*

Nature of Traffic *Heavy.*

Type of Carpet *3" Granite*

Age of Carpet *3½ years.*

CONDITION :

Is carpet satisfactory ?.....

too rich ?

too smooth ?

fretting on surface ?

disintegrating ?

pushing or waving ?

OTHER SPECIAL FEATURES AND REMARKS : *The part of the road treated is on a steep hill and subjected to heavy traffic. The carpet is in good condition with a surface of even texture which has given the required rugosity.*

Signature

PRODUCTS DEPARTMENT

TAR SPRAYING

Report No. 3.

Date 9th April, 1946.

Council Blankford.

Sprayer No. 05.

Location Blankford by-pass.

(For plan see over)

Approximate area being treated under similar conditions 4,000 sq. yds.

Existing Surface Tarmacadam sealed with fine toppings.

Weather Fine and sunny, rather cool.

Traffic Conditions at time Heavy, rather fast.

TAR : Grade Type ' A ' 100 sec.

Temp. in Tank 225 ° F.

Quantity 5 sq. yds. per gln.

GRITTING MATERIAL :

Type Granite.

Size $\frac{1}{2}$ " - $\frac{3}{8}$ ".

Rate of Application 100/120 (yds. per ton)

Any special comments (e.g. dampness dustiness, etc.) dry & fairly clean.

REMARKS : Road blinded from back of lorry. At commencing only one roller was available and some traffic passed over the dressing before rolling. No appreciable displacement of the aggregate occurred.

Signature

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ABBREVIATIONS

- A.S.T.M. . . . American Society for Testing Materials.
- A.u.T. . . . Asphalt und Teer.
- Bull. . . . Bulletin of the Permanent International Association of Road Congresses, Paris.
- C. & I. . . . Chemistry and Industry.
- C.r. . . . Comptes rendues de l'Académie des Sciences. Paris.
- H. & B. . . . Highways and Bridges, later Highways, Bridges and Aerodromes.
- J.I.M.C.E. . . . Journal of the Institution of the Municipal and County Engineers.
- J.I.P.T. . . . Journal of the Institution of Petroleum Technologists (later Institute of Petroleum).

- J.S.C.I.* . . . *Journal of the Society of Chemical Industry.*
R. & R.C. . . . *Roads and Road Construction.*
Sci. et Ind. . . . *Science et Industrie, Paris.*
T.u.B. . . . *Teer und Bitumen.*

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